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Methods of teaching architecture in virtual immersion

Experimentations for the design studio

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T H È S E

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Affidavit 1

Je soussignée, Maria VELAORA, déclare par la présente que le travail présenté dans ce manuscrit est mon propre travail, réalisé sous la direction scientifique de GUÉNA François (directeur) et de MORAITIS Konstantinos (co-directeur), dans le respect des principes d'honnêteté, d'intégrité et de responsabilité inhérents à la mission de recherche. Les travaux de recherche et la rédaction de ce manuscrit ont été réalisés dans le respect de la charte nationale de déontologie des métiers de la recherche.

Ce travail n'a pas été précédemment soumis en France ou à l'étranger dans une version identique ou similaire à un organisme examinateur.

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Maria Velaora

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I, undersigned, Maria VELAORA, hereby declare that the work presented in this manuscript is my own work, carried out under the scientific direction of GUÉNA François (thesis director) and of MORAITIS Konstantinos (co-thesis director), in accordance with the principles of honesty, integrity and responsibility inherent to the research mission. The research work and the writing of this manuscript have been carried out in compliance with the French charter for Research Integrity.

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The approval of the present doctoral dissertation by the seven-member examining committee and the School of Architecture of the National Technical University of Athens does not presuppose the acceptance of the author's views in accordance with the provisions of article 202, paragraph 2 of Law 5343/1932.

Γραπτή κατάθεση 2

Η έγκριση της παρούσας διδακτορικής διατριβής από την επταμελή εξεταστική επιτροπή και τη Σχολή Αρχιτεκτόνων Μηχανικών του Εθνικού Μετσόβιου Πολυτεχνείου δεν προϋποθέτει και την αποδοχή των απόψεων του συγγραφέα σύμφωνα με τις διατάξεις του άρθρου 202, παράγραφος 2 του Ν.5343/1932.

Special dedication to my mother and father

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Abstract

The use of virtual reality and augmented reality in education, at school and at university, is growing in many fields (medicine, history, geography, science, arts, engineering, etc.). These transformations in teaching methods completely escape the teaching of architecture, which remains strongly rooted in tradition.

Scale, morphology, atmosphere, structure, learning how to observe and the relationship between architecture and its environment are essential concepts that are the basis of teaching, especially during the early years. The acquisition of these concepts by the students is carried out through classical teaching methods which have changed little. We hypothesise that digital realities, such as virtual or augmented realities, can be tools, complementary to traditional methods, which facilitate the acquisition of these concepts thanks to the new interactivities they allow.

For example, the immersion in virtual environments, offered by VR, would make it possible to confront the student with various situations and thus develop their perception of space more quickly. The possibilities of mixing the real and the virtual, made possible by AR, would promote the appropriation of the relations between architecture and its environment also the notion of scale, which is often challenging to acquire in some students. It would make it possible to develop students' perspective by offering, for example, interactive urban path tools whose scenarios would be configured by teachers.

Other applications are possible, and the thesis aims to contribute to the potential uses of digital realities on which new educational methods of teaching architecture can emerge.

The research method that we developed consisted in the first place of carrying out surveys among students, future students and teachers. The objectives were to reinforce the relevance of using digital realities and specify the nature of the tools to be developed. Secondly, we have developed several tools and tested them in project studios at the University of Athens. Finally, we have synthesised these experiences to identify the possibilities and limits of the use of digital realities in the teaching of architecture.

The manuscript which relates to this research work is structured in three main parts. The first part describes the characteristics of architectural education, and also presents the context around the concepts of mixed realities and the research on this theme applied to design. The second part describes the experiments carried out in the project studios through the use of several tools. Finally, in the third part we present an analysis of these experiments and several prospective elements allowing the implementation of new methods of teaching architecture based on digital realities.

It appears that the central epistemological paradigm of our contemporary culture in architecture principally focuses on the correlation between topological visualization, computational imagery and their multivalent representational and constructional applications.

Keywords: architecture learning, augmented reality, design studio, interaction, immersion, experimentation

Abstract in French

L'usage de la réalité virtuelle et de la réalité augmentée dans l'enseignement, à l'école comme à l'université, se développe dans de nombreux domaines (médecine, histoire, géographie, sciences, arts, ingénierie et autres). Ces transformations des méthodes pédagogiques échappent totalement à l'enseignement de l'architecture qui reste fortement ancrée dans la tradition.

Échelle, morphologie, ambiance, structure, apprentissage du regard et des relations entre l'architecture et son environnement sont des notions essentielles qui fondent l'enseignement notamment durant les premières années. L'acquisition de ces notions par les étudiants s'effectuent à travers des méthodes pédagogiques classiques qui ont peu évolué. Notre hypothèse est que les réalités numériques, telles que les réalités virtuelles ou augmentées, peuvent être des outils, complémentaires aux méthodes traditionnelles, qui facilitent l'acquisition de ces notions grâce aux nouvelles interactivités qu'elles permettent.

Par exemple l'immersion dans des environnements virtuels, offerte par la RV, permettrait de confronter l'étudiant à différentes situations plus nombreuses et ainsi de développer plus rapidement sa perception de l'espace. Les possibilités de mixité entre le réel et virtuel, permises par la RA, favoriseraient l'appropriation des relations entre l'architecture et son milieu ainsi que la notion d'échelle souvent difficile à acquérir chez certains étudiants. Elle permettrait de développer le regard des étudiants en offrant par exemple des outils de parcours urbains interactifs dont les scénarios seraient paramétrés par les enseignants.

D'autres applications sont envisageables et la thèse a pour objectif d'apporter une contribution sur des usages possibles des réalités numériques sur lesquels pourraient s'émerger de nouvelles méthodes pédagogiques d'enseignement de l'architecture.

La méthode de recherche que nous avons développée a consisté en premier lieu à réaliser des enquêtes auprès d'étudiants de l'architecture. L'objectifs étaient de conforter la pertinence d'un usage des réalités numériques et de préciser la nature des outils à développer. En second lieu nous avons mis au point plusieurs outils et nous les avons expérimentés au sein de studios de projets à l'université d'Athènes. Enfin nous avons effectué une synthèse de ces expériences afin de dégager les possibilités et les limites de l'usage des réalités numériques dans l'enseignement de l'architecture.

Le manuscrit qui relate ce travail de recherche est structuré en trois grandes parties. La première partie décrit les caractéristiques de l'enseignement de l'architecture, aussi présente le contexte autour les concepts des réalités numériques et les recherches sur ce thème appliquées à la conception. La seconde partie décrit les expérimentations effectuées dans les studios de projet à travers l'usage de plusieurs outils. Dans la troisième partie nous présentons pour terminer une analyse de ces expérimentations et un certain nombre d'éléments prospectifs permettant la mise en place de nouvelles méthodes d'enseignement de l'architecture basées sur des réalités numériques.

Il semble que le paradigme épistémologique central de notre culture contemporaine en architecture se concentre principalement sur la corrélation entre la visualisation topologique, l'imagerie computationnelle et leurs applications représentationnelles et constructives multivalentes.

Mots-clés : apprentissage de l'architecture, réalité augmentée, atelier de projet, interaction, immersion, expérimentation

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Glossary

VR: Virtual Reality

AR: Augmented Reality

MR: Mixed Reality

VE: Virtual Environnent

IVE: Immersive Virtual Environnent

3D: three-dimensional

2D: two-dimensional

BIM: Building Information Modelling

CAD: Computed Aided Design

PC or pc: personal computer

DS: Design Studio

EU: European Union

@postasis platform

BII: Behaviour Interactive Interface

Introduction

The education of the architectural design workshop, therefore Design Studio (DS), is considered a signature pedagogy (Ioannou, 2019). DS education is the place where "a professional situation is reproduced in an academic context" (Masdeu & Fuses, 2017), while Shulman (2005) points to a pervasive type of teaching "that organizes how future practitioners are trained for their profession". There is still an ongoing debate among architects and architecture teachers about the role of architectural knowledge and research as a discipline and profession (Salama, 2015).

Researchers suggest that the design studio itself can be classified as Problem Based Learning (PBL) because the starting point for learning in the studio is a design problem that architectural students are likely to face as future professionals. Students are expected to acquire knowledge organized around design issues rather than design disciplines, individually and collectively. The design studio (DS) falls into the category of Problem Based Learning (PBL), given that learning processes require critical thinking, self-reflection, self-assessment, interdisciplinary, self-directed learning and poorly structured problems (Schön, 2012). Henceforth, architectural students acquire significant responsibility for their education.

Most learning tasks take place in small groups rather than lectures. Researchers (Schon, 1992) have also stated that the design process involves a dialogue between designers and their design. This concept of "Reflection in Action" has been used in architecture.

Computer-Aided Design (CAD) and digital 3D modelling software have radically impacted architectural design teaching (Al-Matarneh & Fethi, 2017). Architectural education integrates the training to different types of software such as Autocad, Rhino, GrassHopper, Revit, Sketch-Up, Form-Z, etc. Architectural students also learn to use graphics software editors, such as Adobe Illustrator and Photoshop and rendering systems as 3dsmax, Vray, Twin- motion etc. In addition, students sometimes use alternative open-source software such as Blender, Gimp, Krita, Inkspace, Vecteezy etc.

CAD and graphics software help the production of drawings and facilitated the communication between different actors of building construction sector (architects, engineers, constructors, etc.). However, the design in terms of ideation is generally not done in CAD (Dorta, 2007).

Although CAD has been introduced in most architectural design departments, students cannot use it unless they complete the first year of the architecture training program.

CAD is not considered a tool that values enough three-dimensional space design, and its primary and most popular use is for two-dimensional representations. Thus, architectural students, especially in the first years of their studies, are encouraged to deepen their design and understanding of 3D space by creating geometries and physical models on a scale, perspective design and sketches that illustrate spatial relationships significant for architectural education. The extensive use of design and illustration software can create a cognitive load that often paralyzes or delays learners' creativity.

Therefore, in most countries the Academy considers that architecture students must learn the basics of hand drawing. However, in the second to fifth year, they encouraged the two design methods (manual and digital), which are traditional tools and CAD. Although this transition is not addressed, students can therefore not implement this mix of methods when necessary. The current concept of teaching architectural design is a mixture of the traditional way of designing on paper and the modern practice of using CAD in the design process.

In addition, traditionally, architects were designing on a specific scale that they defined at the beginning of the conception. This process revealed the relationship and the analogies between the object of design and the designer. We can claim that this is a rather anthropocentric process of initiating architectural creation. On the contrary, with the exhaustive use of CAD, especially in the early stages of education, the learner designs in an infinite environment with no specific prearrangement of scale. The constant "zoom" in and out of the design object destabilized the designer and led the architect to design on a scale unknown. Then, the stability of the architectural object in design is eroded by a vital internal force from the designer. Thus, it is challenging to consider the relationships with the human scale. The process of design from anthropocentric shifted to computer-centric, and the students moved from learners to software users. Since the designing scale can be set at the end of the designing process, before printing, CAD can cloud the judgment of what design details should appear in specific drawings.

On the other hand, architecture can be perceived as "a great hollowed out sculpture, inside which man penetrates, walks, lives", writes Bruno Zevi (1957). The usual method of architectural teaching lacks spatial education since the architectural volume is often represented according to decomposition into plans, facades, sections, which contain and divide it (Zevi, 1957). This suggests a need for tools that allow students to walk around and visit their architectural models. But the current design tools, such as CAD and illustration, limit 360-degree views in the architectural design project. Even though CAD models offer design accuracy, they sometimes reduce designers' perception (Stacey & Eckert 2003).

This thesis argues that the transition to new digital media has been vague and largely ill-defined, causing several pedagogical problems. The dysfunctional relationship between the tools and the final tasks envisaged resulted in a separation between the architectural design and the context of the project (Yehuda, 2008; Al-Matarneh, 2017), particularly its sense of scale and proportions. This problem led to a low level of spatial quality of experience and disproportionate reliance on illustration techniques. The inappropriate use of digital tools and the high dependence on them, the lack of integration between the different digital devices and the lack of effective coordination between theoretical courses and design projects resulted in relatively poor and weakened the overall architectural design teaching.

Aware of this problem, university researchers in France and the United States have experimented with software called "game engines", such as Unity 3D and UnReal Engine, used to create video games, and Virtual Reality (VR) and Augmented Reality (AR) applications for teaching architectural design (Lescop and Chamel, 2020). This thesis can be seen as a continuation of these research works. Can immersive environments, as we encounter them in VR and AR applications, improve the process of teaching architecture? This is the main question of this thesis. Mixed Reality (AR and VR) media offer immersive virtual environments for education in various fields. Knowing that the technology of Mixed Reality media exists, it has been easily accessible for the last ten years; there has been a proper environment to reinvest in methods that combine architectural education with immersive and interactive digital tools.

Our research hypothesis consists of digging into immersive environments and testing different applications of mixed realities for the assistance of architectural design education. Mixed Reality applications during the design studio can become an optimal teaching tool that facilitates spatial education and the evolutionary transition between traditional and experimental methods. We are investigating the possibility of developing digital tools that assist learning architecture with mixed reality media.

The introduction of immersive tools during architectural design has contributed to reshaping the modalities of developing new modes of representation (Dorta & Taouai, 2021). According to reviewed articles (Milovanovic et al. 2017) concerning the uses and the potentials of VR and AR in architectural learning, there is 16,7% about VR and 14,5% about AR, of articles concerning applications and systems that focus on the education of architecture with mixed reality media.

Teaching tends to incorporate mixed reality approaches where traditional projects coexist with methods oriented towards computer design. Hybrid reality applications provide immersive environments that allow designers to work alone or in teams with large-scale immersive 3D sketches (Dorta & Taouai,2021). The use of immersive environments has shown several advantages, as they improve the understanding of proportions and scales and the evaluation of design proposals (Beaudry-M et al. 2018, Dorta & Taouai, 2021).

Certainly, immersive tools such as Benchworks (Seichter, 2004), CAP VR (Angulo, 2015), the Immersive Environment Lab (Kalisperis et al., 2002) are examples that integrate mixed reality into the classroom. In addition, there are hybrid platforms like HIS (Dorta, 2007) and Hyve-3D (Dorta et al., 2016), which are immersive systems that facilitate co-design and model creation in VR, enable interaction using portable devices. This type of digital tool is designed to transform the Design Studio classroom into an immersive space.

Research experimenting with advanced technologies suggests that the AR-based method improves the effectiveness of learning in education (Oluwaranti, 2015), as the latter promotes the direct relationship between designer and physical environment. Research also shows a higher degree of satisfaction through AR technology and improved engagement and motivation (Redondo et al., 2013).

The correct use of these technologies has improved the learning process of students in architecture and building engineering degrees (Redondo et al., 2013). Tools like Archeoguide system (Augmented Reality-based Cultural Heritage On-site GUIDE) and VAreal Web Platform (Virtual and Augmented Reality) to introduce AR and VR to the cultural sector (Loumos et al., 2018). In addition, augmented reality applications assist interior space design (Hsu et al., 2013) and urban-scale planning (Broschart, 2015; Cirulis, 2013). It is a powerful visualization tool that projects, infiltrates and simulates reality.

AR applications existing for BIM (Building Information Modelling) that mix the digital augmented space of building construction information and the natural environment with 3D model rendering through an online data platform (Meža et al. 2014; Wang, 2012). Augmented Reality assists the teaching of descriptive geometry, engineering, computer graphics and design training (Voronina, 2019), undermining its use as an entertainment tool or marketing.

AR and VR seem to be robust visualization tools that can assist the teaching of architecture, especially in the early stages of studies. However, in teaching architectural design, very few studios still benefit from these technologies in real practice. Our approach focuses on using devices students use daily, such as laptops, smartphones, and tablets. The teaching of architecture with Mixed Reality media focuses on the relocation of the project, telepresence (Azuma, 1997) and the possibility of interacting in situ during the project's design. In addition, immersion in architectural design on a 1:1 scale facilitates decision-making at the functional and formal levels. AR applications make it possible to adapt pedagogical approaches close to locating learning (mobile learning–situated learning). Therefore, can we propose interactive visual settings of AR allowing situated learning, design and graphic design training with active on-site representations of the project?

Our research method was to experiment with AR tools in design studios. During our two-semester teaching experience in the National Technical School of Athens (NTUA), in the DS course, we found that the teaching nature of the project misses the use of digital tools with immersive environments that allow navigation in architectural design. We interviewed 97 architecture students. 79,2% of students declared that they have difficulty understanding the scale of the project and making transitions between different scales (e.g., 1:10, 1:200, 1:500). In addition, when asked if they believe that Mixed Reality applications (VR/AR) (Milgram, 1994) can help them improve their spatial perception, 60% answered positively, while the rest, 40%, do not know. In conclusion, students believe that immersive VR/AR environments can resolve design challenges or improve the transition from manual to digital design.

Our participation in the MIM team, Cnam in the CÉDRIC laboratory, and our collaboration with the University of Paris 8 allowed us to closely study the structure and mechanisms of immersive virtual environments and interactive digital applications. By exploring the relationship between digital applications and the city, we developed our methodology.

We have developed five examples of IT solutions to support the design studio course (as executable archives) with Unity 3D software. Our digital experiments are the means implemented to answer the research question around using a specific digital tool for learning in architecture. We tend to insert into the design studio (DS) the use of immersive and semi-immersive environments to restructure the process of architectural learning. The applications we have developed are the following: 1) Folie Numérique N.5, Co-learning in architecture with the use of interactive hyperlinks, 2) Behaviour Interactive Interface plug-in, 3) Visit the Unbuilt, Virtually Real,4) Pixel People–Data Parcours, and 5) ARtect. The last two experimentations concern AR applications.

We developed the first three examples as part of the European project: @postasisVirtual Artistic Laboratory. This framework is a webinar teaching method through the 3D real-time and multi-user platform, where the scholarly output is part of Open Educational Resources (OER). The focus was on designing interactions in the virtual environment based on design analysis, simulated behaviours in the virtual environment, and applying these assets to the actual educational practice of Design Studio with students from NTUA.

In addition, we pushed the research towards the development of AR applications for architectural design teaching assistance. Moreover, the integration of AR content functions concerning geolocation coordinates (GPS). We have recreated architectural tools that involve basic CAD commands in AR (e.g., displacement, rotation, scale). ARtect application was conceived to build volumetric spatial relationships in AR. The digital model perceived in 360-degree view can be used at the different stages of the project as a "preview" in real-time.

The digital tools we tested and developed during the research are different applications; however, the educational models of reflection are part of a single sequence. The five demonstrations we set up are part of a sequence of experiments between the years 2017-2021. Each demonstration is an independent digital application also part of the methods that we employ to integrate Mixed Reality tools into architectural education.

This document can be seen as the report of our experiment-based research work. It is structured in three parts.

Part 1 presents main learning theories that concern architectural education and the Design Studio course as the fundamental educational practice for architects. We demonstrate difficulties and particularities in this pedagogical method. Moreover, we present the Mixed Reality media tools that assist architectural design in conception, collaboration and communication during the learning process. Further, we deliver our learning and teaching experiences in Design Studio. Finally, we demonstrate results from questionnaires conducted with architectural students at the National Technical University of Athens (NTUA).

Part 2 presents five educational applications that we developed as teaching proposals based on the integration of virtual immersion for architectural education. The reconstruction of the traditional teaching methods in the Design Studio aims to implement immersive and interactive virtual environments to improve design skills and raise awareness. In this part, we developed these experiments as digital tools to assist the learning of architecture.

Part 3 presents an overall analysis and synthesis of our experimentations, based on the levels of immersion and interaction that each application offers.

Part 1: CONTEXT

This part of the thesis discusses the overall context of the subject. It includes chapters demonstrating that mixed or hybrid learning practices that combine manual and digital methods about teaching architecture can benefit the learning process.

We discuss learning theories such as behaviourism, cognitivism, constructivism experiential and discovery learning. Moreover, we present learning theories that emerged from technology, such as cybernetics, connectivism and mixed learning models. In order to provide the context of our research, we relate the evolution of these theories to the evolution of teaching architecture. Mainly, we focus on the course of Design Studio (or project design) for architectural students. We analyse the particularities and the difficulties that emerge in one of the most dominant courses in architectural education. Furthermore, we observe the evolution in this course through the integration of digital media in the learning practice, such as Computer-Aided Design (CAD), Virtual Design Studio (VDS), and Virtual Reality Aided Design (VRAD).

We present the Mixed Reality concept and its main characteristics and variables of this media form. We explore several systems and applications of VR and AR that are designed to assist architectural education. Mixed Reality systems such as Hyve-3D, CORAULIS and Simulation Lab shape immersive virtual environments for the teaching of architecture.

Lastly, we present tools concerning spatial analysis that we used during the teaching experiences in Design Studio in NTUA. We provide a synthesis of our experiences, also the results of a questionnaire survey conducted with architectural students.

Chapter 1: Evolution of learning theories

1.1. Learning theories

In this chapter about *Learning Theories and Design Studio*, we explore two parallel questions. The first axis of our questioning focuses on the pedagogical transmission of knowledge, and the second, which media assist this passage.

Learning is different from teaching, as learning focuses on the learner rather than the teacher. Learning is considered a continuous and permanent process for everyone and concerns an intentional *change* (Sequeira, 2012). This change involves modifying behaviours, acquiring new skills, and developing new strategies and attitudes. The three criteria considered essential for the learning process relate learning with change, endurance over time, and experience (Schuck, 2012). According to Schunk's taxonomy of learning theories, the primary learning theories are separated into two categories: the ones derived from philosophy and those derived from the science of psychology (Ioannou, 2019). In the general outline of his analysis, the dominant tendencies that derive from philosophy are Rationalism and Empiricism and Gestalt's Theory. At the same time, in the second case, these are the tendencies of Structuralism and Functionalism.

Learning is an educational issue since it concerns gaining knowledge and processing information. Learning yields subjective and objective images of the external world (Guney & Al, 2012). In addition, the resulting subjective images also provide different approaches to learning theories, as explained below, using learning guidelines such as analogical learning in terms of comparability in some respects, by reference, by discovery, and by interpretations. (Guney & Al, 2012). There have been developed theories to describe how people and animals learn; to understand the complex process of learning.

Briefly, the most common theories are, namely, objectivism (Thomas & Kelley, 1999), behaviourism (Skinner, 1953), cognitivism (Gagne, 1984), constructivism (Boyle, 1997), experiential learning (Kolb, 1984), discovery learning (Bruner, 1973), activity theory and expansive learning (Engeström, 2009) (Guney & Al, 2012; Ioannou, 2019).

In addition, theories exist that emerge from Social Learning, such as Cybernetics (Wiener, 1989) and Situated learning (Brown, 1989). Finally, we obtain the theories that emerge from technology, such as the Theory of Chaos (Baker, 1995), the theory of Complexity (Levy, 2000), and Connectivism (Siemens, 2004; Downes, 2012).

Through the Learning theories, and as they have been evolved, researchers observe the way through which we learn to create a teaching method. The key element to comprehend here is that what changes from one learning theory to another is the perception that collective knowledge becomes more and more "central" towards the students (Ioannou, 2019), from constructivism to contemporary connectivism. Scientists observe a shifting from "teacher-centred" education towards a "student-centred" learning process. Another aspect is that the quality of participation changes and the “accountability in learning” (Ioannou, 2019). The training subject (learner) receives greater responsibility in the learning process.

1.1. Behaviourist learning theory

Behaviourism is derived as a learning approach and a combination of psychology, philosophy, and methodology elements. Social Learning Theories, and mathematical theories as Graph theory and Chaos theory, are further explored in the field of behaviours studies as its framework emerges from the systematic method of comprehending human and animal behaviour. In education, within the behaviourist view of learning, the teacher leads the class towards predefined conditioning through the operation that can be distinguished in four categories (Skinner, 1937), positive reinforcement, negative reinforcement, positive punishment, and negative punishment. This operant conditioning focuses on environmental management with the ultimate goal of altering and controlling behaviour. This framework has met various applications such as clinical analysis, informatics, and computing perspectives, and it concerns the design of the new behaviour in the same or new environment. It is related to a simplification of form back in the 1930s and the ornamental subtraction of buildings.

The educational facts, stated by Robert Gagne are gain attention, elements of surprise (stimulate recall of prior learning knowledge and present stimulus with content materials), questions that provoke reflection (provide learner guidance through examples, elicit and access performance through practices and activities) and engage students in responding to other students (enhance retention and transfer of knowledge).

1.2. Cognitivism

The main hypothesis of cognitivism is that thought becomes better perceived in terms of mind representational structures and from calculation processes that function according to these structures (Thagard, 2018). Learning is explored as an internal intellectual phenomenon; it can alter the behaviour but mainly provokes a change in comprehension (Reeve, 2012).

This theory suggests emphasizing what occurs in the learner's mind rather than observing the learner's behaviour (Ioannou, 2019). Supporters of this theory perceive learning as an internal change in understanding knowledge, not as a change of behaviour. The most solid suggestion about cognitivism is based on Bloom's taxonomy, which sets six main goals about the learning process: knowledge, comprehension, application, analysis, synthesis and evaluation. Later, Bloom's ancient students reconsidered Bloom's taxonomy putting in the basis of the taxonomy the learner's memory. Thus, the reconsidered scheme described the following six main goals: remembering, understanding, applying, analyzing, evaluating and creating. The fundamental change that Bloom's students suggested is that the final goal of cognitivism, which was to evaluate knowledge, was replaced by the creation of knowledge (Ioannou, 2019).

"The designer's capacity for perception and information processing is limited. Keeping the cognitive load below this boundary is necessary to avoid major degradation of performance concerning the essential objectives of the design task" (Dorta, 1998). Henceforth, low cognitive loads can increase creativity and the production of new knowledge.

1.3. Experiential Learning

Another of the most widespread revisions of Cognitivism due to David Kolb is known as the theory of empirical learning. The term empirical connects theory with social psychology's beginnings and emphasises the vital role of experience in the learning process (Kolb, 1981). For Kolb, the knowledge cycle is based on experience, and learning is the process where knowledge is generated by the transformation of experience (Kolb, 1984). Experience alone cannot be considered as knowledge but is the basis for its creation.

The theory is based on six fundamental principles in the production of knowledge. Kolb's model includes two ways of understanding experience: The Concrete Experience and the Abstract Conceptualization and two ways of transformation of experience: Reflective Observation and Active Experimentation (Fig.1). The cycle evolves around these two dialectical pairs: on the one hand, those solid and direct experiences are valuable for the creation of meaning and the validity of the learning process. On the other hand, the model is based on action research and laboratory teaching characterised by feedback processes. The transition from one to the other presupposes four basic learning skills, which Kolb calls learning styles, arguing that each student displays a greater or lesser ability in each of them (Ioannou, 2019).

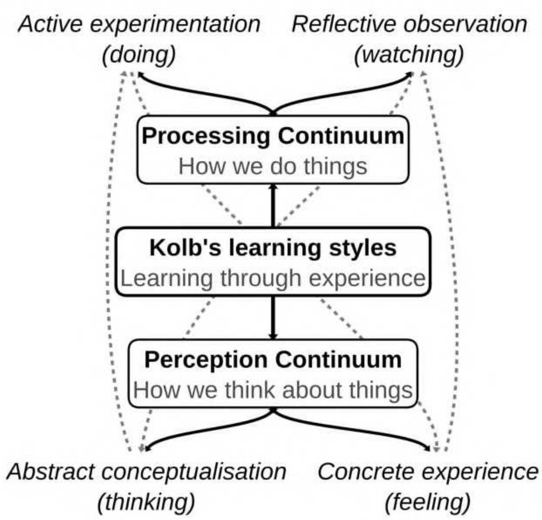

Figure 1. Kolb's learning styles.

1.4. Constructivism–Deconstructivism

This theory emphasises the idea that every individual forms a perception of the world based on the added accumulated experiences and on the person's knowledge and system of values. The consciousness of free will and its social impacts exist at the core of a constructivist learning method.

The notion that humans shape their perception of the world based on their experiences and personal knowledge is the guideline for the development of constructivism. This theory emphasises the importance of conscience, free will and social influences. In constructivism, students learn individually or socially by transforming information (Slavin, 1997), and so knowledge depends on and is constructed by the observer. Cognitive processes of knowledge construction contradict the common assumption that knowledge is effectively transferred from the teacher to the student. The already existing knowledge and understanding parameterise the student's knowledge. Each new information is projected, creating either a deepening of the knowledge or the revision of the previous one. Logic is only one of the ways of perceiving reality, and knowledge is subjective and relevant to the individual or community as it works best in human interaction (Carson, 2005).

Deconstructivism refers to the continuous approach, to the "diachronic" movement of meaning and thus of conceptualization. It is highly facilitated through multiple 'layering' of design, in manual conventional or computational design. Architects like Zaha Hadid and Bernard Tschumi applied this theory in their designs.

1.5. Discovery Learning

Discovery Learning is highly related to social interaction. Any object can be taught to any child at any age if presented in an appropriate form (Bruner, 1973). The ways of thinking or systems that the learner uses to understand information and to develop cognition are based on:

- system of practical representation: sensory-motor intelligence,
- system of symbolic representation: when actions are retained in mind through images,
- system of symbolic representation: when language and other symbolic systems play the dominant role.

1.6. Cybernetics

The theory of cybernetics emerged simultaneously as the (Social) Systems Theory. It started from the idea of automation in mechanical and electrical systems but later expanded to social and educational systems (Ioannou, 2019). The cybernetic approach attempts to describe and understand how the brain functions, determines factors of disturbance and creates mechanisms to study phenomena and maintain systems flow.

Gradually during architectural design, new concepts emerge, such as complexity, infinite space, computational design and randomness. The digital philosophy partially integrates new cognitive operations that designers do when they create space or 3D models. Christopher Hight, in his book *Architectural Principles in the Age of Cybernetics,* provides a historical framework about the relationship of modern architecture within a contemporary philosophical and technological context. Cybernetics focus on methods and activities where the observer is the participant[1]. This effect can be furthered applied in the learning process during architectural conception, with a combination of virtual and augmented reality tools.

1.7. Connectivism

Connectivism is the cognitive theory developed by George Siemens and Stephen Downes in the early 2000s. For Siemens, connectivism embodies the principles explored by theories of chaos, networks, complexity, and other self-organisation theories. For Downes, connectivism describes the conditions that lead to knowledge in a network of synapses as a characteristic of the human brain (Downes, 2017).

The concept of immersion is particularly used by Downes, who argues that learning is not composed of the simple collection of data but is a universal situation where the learner becomes one with his environment: when from 'learning to do' it passes to 'I learn to be.' This for Downes is made possible by the openness of online education.

The concept of immersion is not unknown in architectural studies; however, it is understood completely differently. In architectural schools, the concept of immersion is understood as a laboratory of design where architectural students are entirely devoted to the curriculum and primarily to design workshops, a condition that usually translates into prolonged, exhausting working hours and a continuous presence and exchange between fellow students.

This is a recent learning theory that emphasises networking, the Internet of Things and digital technologies. In this framework, learning does not simply occur within an individual but can be found outside of ourselves by connecting specific data or information. Known teaching methods of this approach are the “Massive Open Online Courses” (MOOC). These online teaching approaches can also be hosted in virtual environments of Massively Multiplayer Online Role-Playing Games (MMORPGs) like *Second Life*. As a new methodological approach, this theory was criticised for missing important concepts, such as individual reflection and learning from failures.

[1] Learning about complex systems when you also live in them is difficult (Sterman, 1994).

1.8. Online Collaborative Learning Theory

The idea of Open Educational Resources (OER) describes any educational resources (including curricula, course materials, educational books, multimedia applications, podcasts, and any other form of material) that are openly available, without the accompanying per payment of royalties or licenses. Their name indicates that the source is free to use, that it has not cost, and that the user has legal permission to modify this source. This range of properties is attributed in English with the term 'the 5Rs,' which in turn is broken down into the legal right to retain, reuse, revise, remix and redistribute (Green, 2016).

Open Educational Resources are defined by UNESCO, 2002 as technology-enabled, open educational resources for consultation by a community of users for educational purposes. OER are accessible and available over the Internet. Their principal use is by tutors and educational institutions to support course development, but students can also use them directly. Open Educational Resources include learning objects such as scholarly output, lecture material, references and readings, 3D simulations, experiments and demonstrations, as well as tutorials and teachers' guides (Wiley, 2007).

In this chapter, the reader had the opportunity to traverse the main learning theories and the more modern theories born within the Internet and web.

Next, we examine Design Studio as a learning process, a course that combines these theories in an experiential framework of practice. We will explore the particularities, the difficulties of this practice. Design Studio has been impacted a lot by the digital tools for design, and thus it is necessary also to examine mixed reality learning models.

1.2. Design Studio as a learning process

From the perspective of Technical Rationality, professional practice is a process of problem-solving. But with this emphasis on problem-solving, we ignore problem setting [...]. In real-world practice, problems do not present themselves to the practitioner as givens. They must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain.

Schön (1983), The reflective practitioner

The course, often called "studio", refers to clusters of students and one or two professors. Design Studio in French is defined as "atelier" and in Greek "σχεδιασμός". All three words refer to a place, a class or a laboratory where the main purpose of teacher and students is to produce and research design. Primarily, the design studio describes the process of architectural education and the origins of this practice. Highly attached historically, studies in architecture were very similar to studies in Fine Arts.

Design Studio has been the primary and most dominant educational tool in architectural education since the foundation of the Ecole des Beaux-Arts (1809). Napoleon founded the Ecole des Beaux-Arts in 1809, while the Ecole Polytechnique was founded earlier in 1794. The schism of these two different schools concerned and questioned the architect's education and the relationship between an architect and an engineer (Giedion, 1982; Ioannou, 2019).

The architectural pedagogy and the courses of that era reproduced an older version of teaching through the "coaching" of students in individual design subjects (Ioannou, 2019).

Throughout history, the fundamental difference in the Design Studio exercise consisted of designing subjects for students, transitioning from real constructions to drawing on paper. In the early nineteenth century, the Design Studio exercise was closer to the profession of the architect, as students were participating in the design of ongoing constructions. The Design Studio course was removed from the actual sites and ongoing buildings in the following century. The exercise then became a process completed on paper rather than being involved in constructing a building. During this century, the Design Studio space was transferred from the actual space to a virtual space of conception.

The virtual design subjects (themes) are evaluated from a more "objective" and "fair" prism (Ioannou 2019; Webster, 2004) in front of a jury of experts, where the student presents himself/herself in defending the design project, rather than the professor as it occurred before the middle of the nineteenth century. In addition, architecture was one of the first professions that used "problem-based learning" (PBL) as the main educational tool (Webster, 2004).

Design Studio is considered as a *particular educational practice*[2]. It is related to professional conditions that are reproduced in an academic environment (Masdeu & Fuses, 2017). This implies modified conditions related to real-life such as urban regulations, maximum surface cover, and building performance. This pedagogical strategy combines activity (Crowther, 2013). Design Studio is characterised by insecurity, the absence of a central figure in the class, students' public exposure, and intense experimentation (Crowther,2013). The learning in Design Studio can be achieved through memory learning but principally through observational learning. As no books exist, students do not have to memorise and take examinations at the end of the semester. There are no written exams in DS, and students just have to deliver the project. Instead, we focus on learning through observation, where the students try to "see" the world from a fresh perspective each time and suggest spatial solutions, organisation and priorities.

Through observation, students accumulate, store knowledge and the cognitive load through memory by experience. This process activates a "pattern" of memory for the student rather than a "database" of memory. The students start experiencing the space and relation of produced spaces by observing the real 3D world, rather than memorising texts of drawings by heart.

Architectural, urban and landscape design are considered non-linear and ill-structured fields of knowledge (Khorshidifard, 2011). Thus, architectural education differs from other clearly structured sciences and other disciplines.

The DS also focuses on dialogue, collaboration and the practice of student communication through images. The essence of pedagogy in a studio is, finally, the criticism, the open exhibition of student work in front of an audience.

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[2] Signature Pedagogy, this characteristic practice derives either from a specific cognitive field (Laudrillard, 2012) or forms of educational practices related to specific professions (Shulman, 2005).

Thus, the DS concerns three types of learning:

1. learning about design,
2. learning design and,
3. learning to become an architect (Dutton, 1991).

Schön observed that the theory that is being used in practice is not identified as academic knowledge. However, professionals built the theory based on their experience through the *act of reflection* (Moon, 2001; Ioannou, 2019).

As a teaching and learning process, Design Studio is considered non-linear (Khorshidifard, 2014) since it implies a circular process of developing and representing design ideas. The main focus of the architectural studio is to provide an environment and the conditions of learning and teaching architectural design, and emphasis is given to the deeper understanding of the students' needs and, on the ways, the latter can be more effectively engaged. Studies conducted across Australian Universities in 2007, several pieces of research reveal the significance of architectural design, as it "occupies about 38% of the entire curriculum" of architectural studies (Iftikhar, 2018).

In addition, the non-linear educational process highlights the importance of students' and teachers' interactions during this learning process (conversations). Usually, an architectural project has a certain level of complexity, as many functions shall be included. Therefore, the activity of *spatial conception* is both individual and collective. During Design Studio, the students produce a number of hand sketches (2D/3D views) that aim to search for analogies and the essence of space as they develop autonomy in a) Individual Learning, b) Learning in Groups and c) Learning by distance.

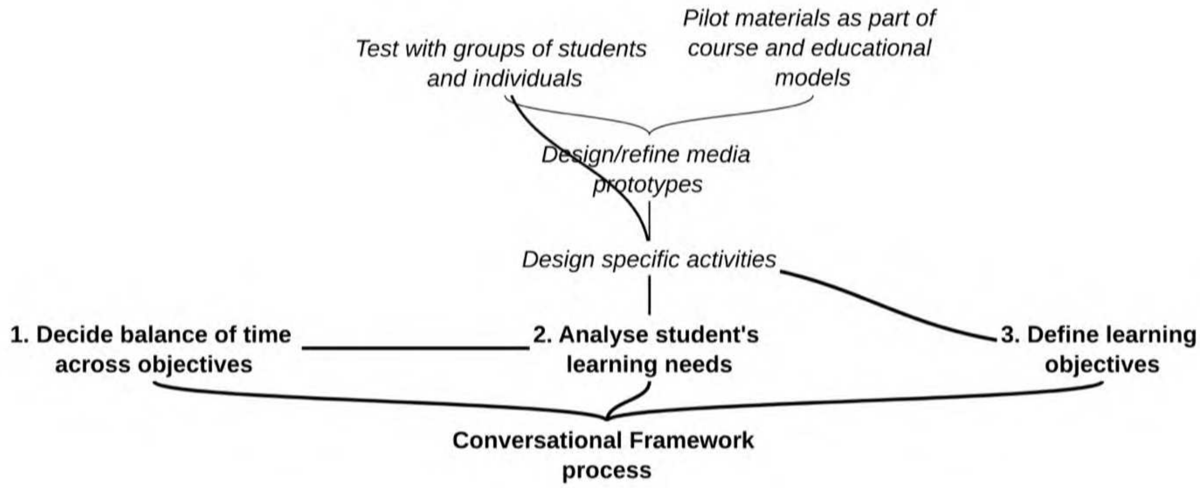

Figure 2. Conversational Framework diagram.

At the end of the design exercise, the students have to deliver drawings on a scale, physical models, sketches, renderings, and presentations of their projects. In the book "Rethinking University Teaching, a framework for the effective use of educational technology," Dianna Laudrillard (2002) utilises the Conversational Framework as a model of teaching, learning and analysing educational media. The approach of situated learning creates *direct relationship between the learner and the world*, placing the role of the teacher as a mediator. The components of this learning theory based on dialogue and conversation (Fig.2) (Iftikhar, 2018) is intended to be applicable to any academic educational framework (Laudrillard, 2002) also, in Design Studio and architectural studies.

Design Studio is an empirical learning process about solving problems.

There is an educational process that tutors follow to transmit learning architectural design to students in these workshops.

Through interpreting ideas of a conversational framework (Iftikhar, 2018) and making an analogy to design disciplines about learning and teaching architecture in an environment of a DS, we present the following stages of an educational process related to the architectural project (Gero, 2004):

1. Verbalisation and description of the project. (scenario, program, narration, language).

Verbal communication constitutes, before sketches, the primary design tool allowing designers to externalise intentions and launch ideation (Jonson 2005; Dorta et al., 2019). The project of architecture starts with the verbalisation of the architectural concept (idea). The concept of the architectural idea represents the dominant principle of spatial synthesis. The first step is *form-finding for the architectural conception*, illustrating the architect's sketch intentions and priorities.

2. A non-verbal form of communication unfolding as the interaction between teacher and students, as a game played among them like a form of a hidden curriculum of appointing roles (Dutton, 1987).

During courses of architectural design studio, the movement of the architect's body, eye contact and the expression impact the design process with non-verbal communication. The relationship between body movement (spatial position, location, behaviour) and design tool is a fundamental part of architectural creation. Similarly, modern architects tended to make large gestures to signify forms. Nowadays, the computer is a tool that imposes physical immobility during the conception and the design of the architectural project. In the virtual immersive simulated environment, the body of the designer participates differently from CAD-design, giving more space for expression as we explore further in this document.

3. Graphical representations and physical models, as the representational ecosystem.

The representational ecosystem is characterised by non-verbal communication (visual, optical senses, neuroscience, cognitive design, immersion) as an act of design. In earlier times, the profession of the architect was directly attached to the construction's sites. Throughout history, architects managed to better represent their conceptions of the architectural object, avoiding more design mistakes. The experiences of Brunelleschi and Alberti with perspective reveal the tendency in architects to develop a method *towards a realistic spatial representation* (Dorta, 1998), even though relativist.

Finally, a design studio as a learning process consists of various media acting as a Graphical Simulation System through which design intentions are exteriorised (Lebahar, 1983) for learning purposes (Dorta, 2016).

4. Online medium.

Online platforms (such as social networks, forums, blogging, channels, webpages, etc.) exist to accompany the educational process of architectural design. Moreover, independent models of mixed learning like open-source platforms and MOOC's (Massive Open Online Courses) can further enrich this process.

The aim is to obtain educational feedback about interfaces that provide:

i. Organisational digital space for design research with virtual scenes and digital models.
ii. Visual representations of research disciplines as mind maps (e.g., Mohio map).
iii. Central platforms and clouds for architectural design education.
iv. World-building scenarios.

1.3. Stages of the educational process

Design Studio combines adaptive, reflective, interactive and discursive non-linear learning processes for architectural design.

We present the stages of the learning process (Laudrillard, 2002):

1. Discursive Process

This is the initial stage of the learning process, where students and teachers use descriptions to define the goal of the exercise. This occurs in Design Studio during the communicative stage of the project by setting requirements and structural programs for the site's building implementation.

2. Adaptive Process (internal)

This process includes internal activities by both the tutor and the student, each of whom adapts their ideas, tasks, and actions according to the descriptive level of the exercise. The tutors set the goals of the design studio exercise and, with the groups of students, adapt to each different spatial approach, priorities and relationships.

3. Interactive Process

At this stage, the students aim to achieve their goals by producing solutions and presenting the axis of action as they receive the teacher's first feedback. During the semester, lectures, seminars, and corrections are taking place and exercises of spatial synthesis and analysis to deepen the design in detail.

4. Reflective process (internal)

The reflective process is internal, as in the adaptive process. Both reflective and adaptive processes reflect on the interaction occurring, validating the teacher's mediation to redescribe students' understandings concerning the initial goal of the descriptive process.

1.4. Difficulties in Design Studio

The DS is based on a teaching model that encourages open practices such as group collaborations and group corrections. However, the learners' interaction within the framework of DS is influenced by the hierarchical relations between teachers and students (Ioannou, 2019). Dutton highlighted the hidden features of this pedagogical approach by describing the power relations between teachers and students.

Dutton claims (1987) that Schön's model about formal discussions with students implies that the teacher's role is to "correct" students' plans and excludes the fact that the nature of architectural education is a dynamic and confrontational field.

The educational structures of the DS reproduce the views and rules of the profession without introducing new material by users or independent observers. This is one main reason why the gap between academic knowledge and professional practice is constantly growing (Duffy, 1998).

In Barr & Tagg's (1995) article entitled "From Teaching to Learning: A New Paradigm for Undergraduate Education", the two authors observe that while many teachers agree to the view that overall, the academy should produce learning (or learning experiences), Higher Education remains attached to the production of teaching. This creates, they say, a significant inconsistency between the way the academy operates concerning the data obtained from the studies of how the learners work and how knowledge is produced (Barr & Tagg, 1995). This divergence, notes Randy Bass (2012), becomes even more pronounced now that our perception of learning has expanded even further and that technologies allow the introduction and integration of highly influential practices.

During any process of learning, learners face their cognitive biases regarding the environment, experience and behaviour. Learning itself is a process of enclosing and enveloping new realities by attaining and employing new knowledge; we examine the design from an epistemological perspective.

This transition from manual to digital design has been traumatic to the educational design studio because the current digital paradigm largely ignores the gap between the traditional and digital representation tools. Therefore, we argue that there is a need to envision a new digital paradigm better integrated with the broader representational environment of the studio (Dorta, 2016). Architects perceive space as layers of spatial elements that are different, recognizable and they maintain a hierarchical order between them.

During the "learning to design" process, several cognitive operations occur simultaneously while using the digital interface regarding manipulating design space as a digital tool and design itself. This process affects the perception of the space or its attributes, such as geometry, structure, scale, material, lighting. Thus, the learner is trained to design at many different levels, maintain a picture of the design, use digital software, and assist architecture discussions.

Architectural design difficulties may concern the perception of scale, proportion, and depth and can significantly impact developing a master plan. The relation between spaces is transformed under the global scale prism. Students are often found paralysed in front of exercises containing urban design. Scales of perspective design views and representations interfere with the 1:1 scale of architecture, as the perspective design is a drawing that simulates and thus constructs reality. Nevertheless, perspective design is representative but not realistic according to what the eye sees.

Moreover, as the whole perception of the city and the landscape changes, teachers of DS often present adjusted conditions concerning regulations about the urban environment different. There is flexibility in the community's policies and norms on an architectural design by several Architectural Committees in the academic framework. The educational environment of Design Studio is an environment that alters the reality of existing laws that are applied for the professional architects in the market in order to become a method for design while, in some cases waiting for the industry to dictate new directions. Little research is applied to the direction towards Immersive Virtual Environments (IVE) for the practices of the DS.

1.5. Virtual Design Studio (VDS)

The term Virtual Design Studio (VDS) describes a way of combining computer-assisted technology and digital communication technologies to reduce or eliminate the need for coexistence in the same place. VDS was made possible thanks to CAD design technologies combined with communication, image, data, and live-action technologies. They offered the opportunity to strengthen cooperation and to diversify students' experiences (Laiserin, 2002).

Their virtuality due to remote communication or specific digital media (Ham & Schnabel, 2011; Schnabel, 2001; Schnabel, 2007) led to technologically oriented practices in the DS. VDS are networked design workshops where teams are found across different locations, all communications occur via computers, and the design product information is digital, as is the final delivery.

Briefly, we mention the VDS's programming principles (Ioannou, 2019):

- the establishment of a new perception between students and teachers that can mediate between perception and reason,
- the creation of a way of thinking that can share and make sense of design actions within the same or different cultures,
- the process to become more accessible, to float like a design game.
- the networking, which soon becomes global, can provide an exciting context for developing a new approach to design that will be team-based, crossing the boundaries of space and time.

Many of those who have made VDS argue that they are not effective or necessary as means of design: technology is not cheap to acquire, and at the same time, it is difficult to support it. The problems of communicating within a computer network increase exponentially depending on the number of participants (Kvan, 1997). However, despite the developments in communication technology, the gap between teachers and students that theoretically is filled by the computer remained noticeable.

As far as computer intermediation is concerned, Gross and Do (1999) describe the application of six uses of digital technologies in the design laboratory:

1. Computer Augmented DS: the first and most common studio with conventional computer equipment that students use either exclusively or in combination with conventional representational tools (e.g., Photoshop, formZ, Autocad).
2. CAD plus Studio: although design laboratories focus on form formation, computational tools (simulations and analysis programs) can enhance this formation with relevant information from the behaviour of the building.
3. Virtual & Web DS is designed for the exchange of ideas, criticism and drawings.
4. Cyberspace DS relies on what we know about built environments to explore the design of virtual spaces for public and community use; for example, navigation and guidance are important searches in virtual environments.
5. Intelligent Building Studio recognizes that information technology in the form of smart materials, sensors, and microprocessors will become part of the construction of the buildings of the future and prepare the art tectonics accordingly.
6. Toys and Tools Studio: explores the next generation of software production and its impact on architecture.

The VDS demonstrates that the use of shared virtual environments supports synchronous collaboration by distance. Usually, the virtual environment of a VDS is displayed on a desktop, which is considered as a non-immersive representation and virtual environment (Milovanovic et al., 2017). To consider a Virtual Environment as non-immersive has to *maintain limited interactivity*, for example, only mouse selection (by clicking) and limited communication by chat or audio-visual communication by distance. The main characteristic of these environments is separating the digital environment as it coexists with the physical. The course in a non-immersive VE does not necessarily imply the user's physical presence. This technique has been utilized several times, as this method provides a safe and accessible way to share and collect knowledge with free licence (Creative Commons). Lastly, VDS initiative of hybrid space between physical and digital (virtual) dimensions for architectural design provides strict limits in terms of interactivity among the users.

1.6. Mixed Reality learning models

The assimilation of information technology argues Kocaturk (2017), has two dimensions: mediational and instrumental.

In the first case, digital media use includes a mediating platform where formal or informal learning can occur. Tools such as social networks, blogs, open platforms, tutorials and wikis facilitate informal interactions within learners and help them gain skills and access to educational resources. In its most typical form, mediation occurs through Virtual Learning Environments (or in short, VLEs) structured in a way that does not reflect the dynamism of the structuralist and experiential form of learning.

In the latter case, digital media produce knowledge in a tool dimension (Ioannou, 2019). Independent individual examples of a mixture of traditional methods in teaching architecture exist while using online and digital design tools and different communication technologies.

Mixed learning tends to be informal, experience-focused and knowledge-based, rather than formal and focuses on the content and practice of traditional education (Cross, 2006). Mixed learning reflects the blended nature of the world and the natural process of how people learn either alone or in groups (Shagafi et al., 2014).

The advantages of using mixed learning models in architecture, in particular, are the pedagogical variety and the social interaction with fellow students and teachers without being in the same location. The individual is activated if the open access to knowledge and the interaction with learning elements (texts, videos, etc.) are enhanced without the need for physical presence in libraries or dependence on hours. Corrections or critic sessions are facilitated by sharing ongoing assignments, which allow collaborative learning and assessment beyond time and space.

The challenge is how teachers everywhere will acquire these skills to enable these models to spread more widely in the academy (Mirriahi et al., 2015). Without changes in expectations for modern university professors, even when the faculty is innovative, it will be difficult for innovative ideas to enter the dominant practice (Johnson et al., 2014).

Most efforts are characterised by a willingness to spread the course in more than one environment to include the formal and informal activities of the students in the learning process. While initially, the experiments were discreet and used the Internet to deposit learning material, they gradually began to grant more freedom to the participants to contribute to the course content and interact with their classmates.

In these more advanced versions, mixed learning requires information technology, and it challenges some of the most fundamental practices of the traditional design workshop.

Specifically, we can obtain the following blended techniques (Ioannou, 2019):

- typical design workshops with the parallel use of a centrally controlled platform with or without the use of social networks
- typical design workshops using a shared management platform with or without the use of social networks
- design workshops using blogs, social networks and distributed control to all members.

Finally, we can obtain Mixed Reality learning models with the use of Virtual Reality and Augmented Reality media. This is the subject that the thesis explores further.

The teacher needs to know the use of the digital management tools of the course. These learning practices are highly related to the learning process of architecture and art in higher education since many of them are based on visual representations, perception, and technology.

Summary

The architectural learning process is seen as an original, even peculiar method of education, and the influence of technology has been considered ambiguous several times. Digital means of representation and their role as tools have transformed the produced architectural result. Several architects and architectural professors reasonably emphasise the gradual unilateral domination of digital reality concerning architectural construction and, as a result, it is included in the teaching of architecture. The evolution of learning theories shows there is a tendency in education to adopt learning models that combine the traditional tools with the digital tools of Mixed Media.

The common ground of several digital applications is to increase the educational capacity through digital collaboration and communication. We examined hybrid learning theories and models, from traditional behaviourism to contemporary connectivism. It revealed the blended nature of the world and how people learn either alone or in groups. The evolution of learning theories demonstrates the implication of computers and the communication between learners and professors through digital media.

In the next chapter, we introduce the reader to the main characteristics of the Mixed-Reality concept. We will explore the origins of this medium and arrive at the emergence of Augmented Reality that can become a future digital tool for architects.

Chapter 2: The Mixed-Reality concept

The abstract machine of language is not universal, or even general, but singular; it is not actual, but virtual-real.

(Deleuze & Guattari, 1987, Translation by Brian Massumi)

We present the concept of Mixed Reality media, which is based on virtuality, virtual environments and immersion. The reader obtains a historical framework about the evolution of Virtual Reality and Augmented Reality media concerning materials, technologies and devices employed. Furthermore, we present the concept of immersion and immersive virtual environments. Lastly, we present the characteristics and the main features of Augmented Reality. This chapter is necessary for the reader before we proceed to an application of this media in architectural education.

Virtuality is an idea initiated by the French philosopher Gilles Deleuze as opposition to actuality. In 1994, Milgram and Kishino presented a taxonomy of Mixed Reality media, often mentioned as Virtuality-Reality Continuum (Fig. 3). This continuum describes the spectrum of Mixed Realities, where the real environment is opposed to the virtual or digital environment. Several intercourses between this relationship lead to the transition from real space to an entirely virtually synthetic environment (VR). In between Reality and Virtual Reality, there is Augmented Reality (AR) and Augmented Virtuality (AV).

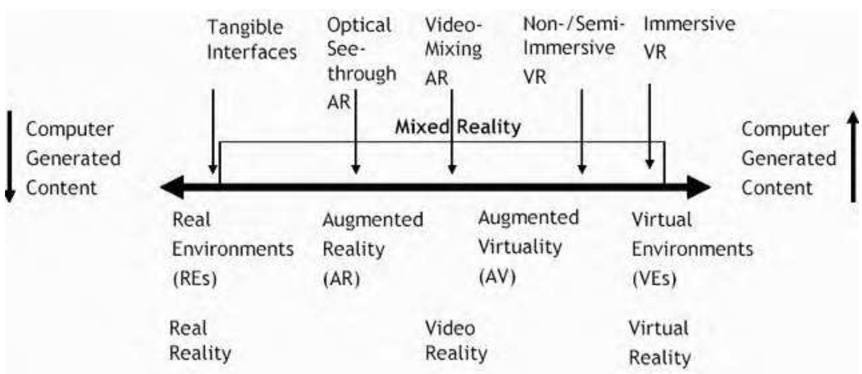

Figure 3. Mixed Reality or the Virtuality - Reality Continuum, Milgram et al., 1994.

Both Augmented Reality and Augmented Virtuality media blend virtual with real-world elements, superimposed into a single user layer interface (screen). The two represent digitally synthetic worlds as opposed to the static or historic built environment. The main difference between AR and AV concerns the interaction of the user. In particular, when the interaction takes place in the real environment, such as a game played in an open-space park, it is considered Augmented Reality (AR). In contrast, if the interaction occurs in the virtual environment in real-time with the real world, it belongs to the Augmented Virtuality category. Such as an aircraft maintenance engineer visualises the fight on the screen while what occurs to the aircraft can be physically kilometres away; the interaction takes place in the virtual space and then impacts the actual space.

The reality-virtuality continuum shapes the digital ecosystem, which refers to interactive media forms of representation, such as augmented and virtual reality, video games, smart systems and (artistic) installations.

The field of VR is highly impacted by representations of visual art, cinema and video games. In this thesis, we consider VR and AR as part of the larger field of Gaming and Video Realities. We examine the tools that an architect can improve and help observe 3D space through interactive applications in 3D immersive environments. The method is to combine architectural studies and Mixed Realities media.

We mention the following states of relating virtuality with 3D space deriving from the following categories:

1. Virtuality is projected (e.g., as a digital mask, dress, painting).
2. Virtuality is captured (e.g., cameras, sensors, scanners).
3. Virtuality is produced (e.g., 3D printing, BIM).
4. Virtuality is complete dissociation from the real place.
5. Virtuality is part of the design, associated with attributes of a place.
6. Virtuality coexists simultaneously with reality.

2.1. Origins of the medium

We focus on VR and AR applications. However, before we deepen into the relationship between architectural studies and Mixed Realities, the author considered it useful to provide a historical framework of these “realities”.

Virtual Reality has been born and dies since 1960, approximately every 10 to 20 years as a concept and practice. Today, in 2021, we traverse a decade where augmented and virtual reality technologies receive more attention and technological progress.

Virtual reality had trended a lot since 2013 when Oculus Rift launched the first Head-Mounted Display (HMD) of VR. Virtual Reality can be experienced through HMDs like Oculus Rift, the HTC Vive, low-cost Google Cardboard and Samsung Gear VR. Furthermore, VR can be experienced within immersive rooms, called CAVEs (Cave Automatic Virtual Environments).

Later, in 2014, Facebook bought the company Oculus and increased the public's interest also pushed the developers towards this field, connecting this media form with cyberspace and the Internet. However, researchers suggest it is worth dissociating the virtual reality concept from the technological advancements related to the field, which means that Virtual Reality is not the computer (Whyte, 2002), but the conditions that permit the emergence of a new reality.

The development of Virtual Reality has its roots before the development of advanced technologies (Whyte, 2002). Over time, artists and designers developed several types of representational means. The brief historical flashback about VR development is to better understand how technological advancement and new means assisted how we perceive the world. Jennifer Whyte (2002) suggests that in the fourteenth century, the innovation of high-quality glass led the world to increasingly being viewed through a cadre (Mumford, 1934).

The cadre (frame) has made it possible to observe reality more clearly and focus on a specific field of view. The development of glass later encouraged innovations, such as lenses and mirrors, that affected how we perceive the world and ourselves.

The developments in lens and mirror technologies and the development of accurate portraits (frames) at around 1420 suggest that the relationship between ways of seeing and the technologies of visualisation is much older than usually described (Hockney, 2001).

Whyte points to great masters of Western Art from that time on, such as Caravaggio, Vermeer, Velázquez, Van Eyck, and Van Dyck about the possibility of using lenses or mirrors to make paintings (Hockney, 2001). In addition, Whyte suggests the cathedral architect in Florence, Brunelleschi, probably had access to the latest and most advanced technologies of that era, including glass from northern Europe and that through experimentation with a lens or mirror Brunelleschi discovered linear perspective (Whyte, 2002). This indicates that the technologies affect how we see and comprehend the world and thus design.

From the seventeenth century, artists created panorama paintings, triglyphs, lunettes (Fig.4), which is an image of an extended field of view, often 360^o unbroken view of a landscape, a scene of a whole region, surrounding an observer.

Figure 4. Lunettes, 16th century. Image from the course of prof. Moraitis, 2018.

Painting, panoramas, frescos, anaglyphs (3D paintings) and, triptychs compile the baseline of the history of the image in architecture. The images in the landscape, city, comics, media, and TV are cultural elements reflecting society and specific systems of values. The observer's position, the eye of the beholder, provides several visual and mental spatial interpretations. The observer's presence indicates the angle as the designer's intentions to unfold a specific "reality check".

Almost three centuries later, new means such as the lense, the camera, the excellent use of electric lighting and the Industrial Revolution, which made transportation and travel easier, helped to captivate the movement and the production of more images by the art of photography. Furthermore, we have the dioramas, which are 3D miniatures.

In the twentieth century, artists gave birth to the art of filming scenes as images in movement. Several representations of reality started to unfold during this century, and several tools started to facilitate communication.

The end of the twentieth century and the beginning of the twentieth-first century is marked by the digital revolution, the addition of the daily Internet use - the most sophisticated human tool until today. In the early 60s, Morton Heilig introduced Sensorama, (Fig. 5, left) which is considered one of the first Virtual Reality (VR) systems. Sensorama is a machine of immersive and multisensory technology. In addition, Ivan Sutherland (1965) introduced the ultimate display (Fig. 5, right) as one of the first Augmented Reality installations.

Figure 5. Sensorama Simulator device (left), Sutherland's Ultimate Display (right).

Virtual Reality and Augmented Reality as perceived today, are actually the third generation of immersive images, after panoramas and dioramas, allowing the observer a spatial immersion in a digital-generated environment (Grau, 2007).

In this century, with the development of holography and devices that support individual digital glasses, such as HoloLens, which is a head-mounted display for augmented reality, it is not impossible to receive the fourth generation of immersive images, the holographic images. Jones and Rogers (1984) presented an arrangement for holographic reconstruction (Fig. 7), also a holographic head-mounted display unit (Fig. 8).

Nowadays, artists started experimenting with holograms, creating models in the 3D digital environment to overlap with the real environment, as the German Circus Roncalli (Katz, 2020) did when it used holograms instead of living animals (Fig. 6).

Figure 6. Circus Roncalli holograms.

We can claim that Mixed Reality media gave "image" its ultimate power by enabling the creation of almost impossible 3D digital environments. With the use of robotics, artificial intelligence slowly transforms the image from painting into 3D digital real-scale holograms. This transition impacts the perception of our environment, our learning and design capabilities, and thus architectural education.

However, while Virtual Reality and Augmented Reality both share some commonalities and often interrelate, they are, in the end, distinct technologies (Kipper & Rampolla, 2013; Whyte, 2002) (Table 1) (Fig. 9).

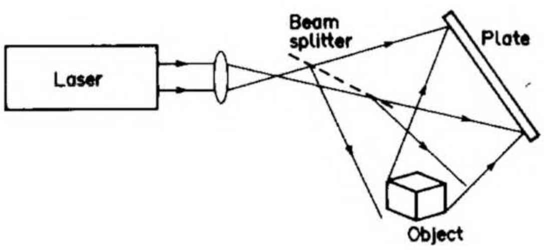

Figure 7. An arrangement for holography, Jones & Rogers (1984).

Figure 8. Holographic HMD, Jones & Rogers (1984).

Table 1. A brief history of AR and VR medium.

Brief History of developments in enabling technologies		
	Virtual Reality	**Augmented Reality**
pre-1950	the first real-time computer, Keyboards, Flights Simulation	
1950-1970	Sketchpad - the first CAD application, head-mounted displays, Computer graphics and human-computer interaction (HCI), including haptics	Sensorama: the first immersive multisensory technology by Morton Heilig (1962), Sword of Damocles, the first example used 6DoF (Degrees of Freedom) trackers
1970-1985	Walkthrough - the first interactive architectural walkthrough, Advanced rendering of 3D objects, Networked computing, Introduction of mouse and joystick	Video place, User interaction
1985-1995	3D APIs, Open GL, Multi-user worlds, gloves, Web-based 3D, VRML 1.0, Basic translation from CAD to VR	Tom Caudell and David Mizell are credited with coining the term "Augmented Reality."
1995-2000	Flat and high definitions screens, mobile devices, CAD to VR and GIS to VR data translation, VRML 97	Jun Rekimoto developed an AR prototype called NaviCam and advanced the idea of the 2D matrix marker (QR codes). Ronald Azuma defines AR, the release of ARToolKit to open source community, wearable AR systems
2000-2013	Motion capture, volume visualisation, motion capture, autostereoscopic displays, 3D laser scanning, Cloud Web	mobile, multi-user AR system, Archeoguide, The Real-World Web (RWWW) Browser is recognised as the first AR Browser, mobile phones
2013-2021	Occulus Rift, Social Media, Head-Mounted Displays, Cardboards	Vuforia, Head-Mounted Displays, AR-enabled glasses, ARCore Google, API Depth

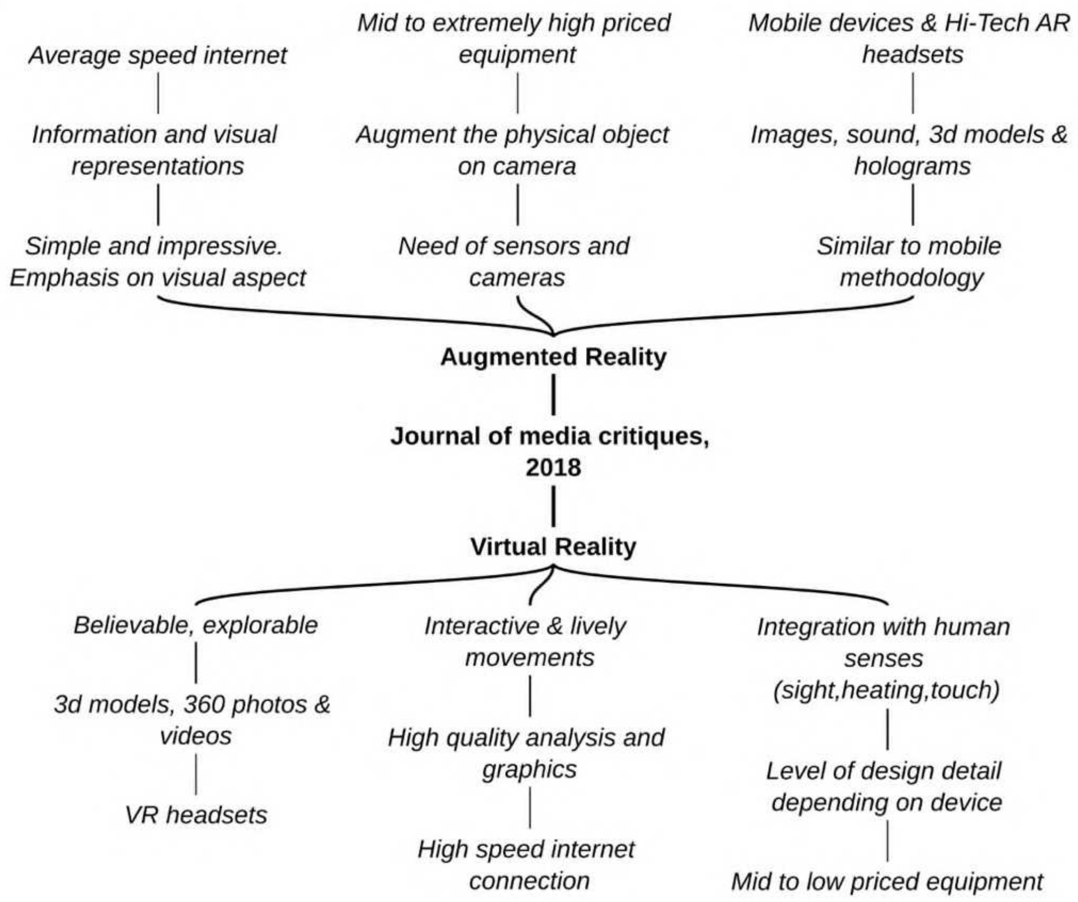

Figure 9. Based on Journal of media critiques (2018). Diagram about AR and VR attributes.

2.2. Characteristics of Mixed Reality media

We detail the essential variables useful for understanding Mixed Reality media. The first step is to present the different classes of environments (Craig, Sherman, & Will, 2018).

Definitions of variables:

- Virtual: (adj) An indication or a meter that an entity mimics and simulates the characteristics; inside a virtual world, any object of the world can be said to be virtual.
- **Virtual environment**: (1) a virtual world; (2) an instance of a virtual world presented in an interactive medium such as virtual reality and 3D modelling software.
- **Virtual world**: (1) The contents of some medium; (2) a space that exists in the mind of its creator, often manifested in some medium; (3) a description of a collection of virtual objects in space, and the rules and relationships governing those objects, such as cyberspace.

- **Immersive Virtual Environment** (IVE): Virtual worlds are three-dimensional digital environments and interfaces accessed through a computer or a specifically designed environment to host an immersive experience. IVEs are considered an extrapolation of serious games—since these are digital (software) applications intended for use beyond pure entertainment, cultivating a purpose.

IVEs are not seen exactly as gamespace, although many design principles, structures and features are often similar. The main difference between serious games[3] and immersive virtual environments lies in the objective: game players are confronted with obstacles intentionally built into the software, while users of virtual worlds and IVEs seek to achieve self-directed goals through engagement and collaboration[4] (Whitney, 2011). The environments of VR and AR applications are considered fully immersive since they engage the learner in a parallel or a new reality.

- **Semi-Immersive Virtual Environment**: Specific environment of VR that allows experiences and interaction in three-dimensional virtual environments while the user remains connected to the real-world surroundings. In this category belong the majority of video games and applications of video realities.

Lastly, we note that in AR applications, the user maintains contact with the surroundings. Still, AR virtual environments are perceived as fully immersive since the user's entire body participates in a spatial experience in the real world.

The next step is to understand the important factors that define a Mixed Reality experience: interaction and immersion.

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[3] The emergence of serious games as a branch of video games has introduced games designed for a so-called "serious" purpose, other than pure entertainment or fun. The significant applications of serious games include education, puzzle, strategy and training, engineering. In addition, Healthcare and military applications are also essential domains of serious games development (Garcia-Ruiz et al., 2011). Urban planners and architects can use this type of applications for training, crisis control, and emergency response.

[4] Whitney Quesenbery, Daniel Szuc, 8 - Bringing it Home, Editor(s): Whitney Quesenbery, Daniel Szuc, Global UX, Morgan Kaufmann, 2011, Pages 155-169, ISBN 9780123785916, https://doi.org/10.1016/B978-0-12-378591-6.00008-4. (https://www.sciencedirect.com/science/article/pii/B9780123785916000084)

Interaction is related to the physical actions by the user to develop communication with the computer and impact the 3D virtual environment. Immersion is related to the 'sense of presence' inside a virtual environment.

Our research focuses on the aspects of Mixed Reality media: immersion, three-dimensional models, viewing perspectives and navigation modes in immersive or semi-immersive virtual environments.

2.2.1. Immersion

The concept of immersion is key to understanding Mixed Reality and the digital culture's integration in architectural design. Immersion is a concept that derives from Social Cognitive Theory and Psychology. The sense of immersion is primarily related to media of Mixed Reality. Heim's definition[5] follows:

> **Immersion:** An important feature of Virtual Reality systems. The virtual environment transfers knowledge as it submerges the user in the sights and sounds of a specific environment. Immersion is the sense of being present in a virtual world beyond physical input and output. How presence and immersion coalesce remains an open question in VR research (Heim, 1993).

In addition, Sherman and Craig (2003) provide a definition where they distinguish mental and physical immersion.

> **Immersion**: the sensation of being submerged in an environment; it can be a purely mental or physical immersion. Immersion is a defining characteristic of Mixed Reality media to develop the user's engagement; mental immersion is a goal of most media creators.

Immersion points to what degree the user can easily adapt a tool, and it is an indicator of adaptability, orientation and participation in a synthetic environment. Immersion also occurs by the access on Internet, Social Media or Wallstreet. Digital culture enables virtual identities, behaviours and flows, creating a second parallel reality. In a way, we are all immersed in Mixed Reality since the Internet became inseparable from daily practice.

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[5] M. Heim, *The metaphysics of virtual reality*. New York: Oxford Univ. Press, 1993.

"Immersion arises when the artwork and the technical apparatus, the message and medium of perception, converge into an inseparable whole"[6] (Grau, 2003; Grau, 2007). Therefore, levels of immersion are increased when the medium becomes invisible by its exhaustive use. The convergence of digital technology with aspects and activities related to the physical world leads to the daily practice of Mixed Reality concepts.

For example, the concept of immersion can be understood through cartography. Digital immersion derives from digital cartography, where materiality is virtual, and the actual geometrical space is augmented by the virtual material, the *digit*. Cartography is the science of design that aims to understand and represent an aspect of the geographical wholeness of the word. “A *map* is conceptually akin to a *propositional network* because mapping involves creating a hierarchy, with main ideas, or superordinate concepts, listed at the top, followed by supporting points, examples, and subordinate concepts” (Schunk, 2012).

The scale of global coexists in permanence with the scale of local in Mixed Reality concept, in different levels of perception and immersion. Although cognitively this is possible, the representation of a map on a 1:1 scale is considered impossible. Applying the concept of scale is needed for the cognitive process of a “reduction” or “augmentation” of the spatial perception. However, in a cognitive level we apply the concept of immersion. The phenomenological approach to modern digital tools by architects raises the question of concepts of place and emplacement concerning the phenomenon of globalization (Champion,2019). The idea of immersion describes sufficiently the complexities that emerge in the digital era, regarding representations, cartography, local and global scale.

In addition, the relationship between the size of the drawn architectural object and the real object of architecture is not only geometric and proportional; it is also a convention that determines the type and the amount of information presented in a particular drawing (Dorta,2016). With the impact of the camera, the connection on the web and several recognition methods used in digital media, the concept of scale becomes a purely geometric concept and not semantic (meaningful) and transformed into a metaphorical language for the architects.

The idea of immersion merits further exploration by architects and professors in architecture. Drawings are often created in ‘full scale’ with CAD (in terms of drawing units)

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[6] O. Grau, *Virtual art: from illusion to immersion*. Cambridge, Mass: MIT Press, 2003.

(Dorta,2016); however, they are viewed in an arbitrary and fluid zoom factor on the screen or projector. This fact describes different levels of immersion into the architectural object. Dealing with architectural scales leads to a loss of reference and scale-awareness for the architectural student when the design occurs in a virtual environment. The learner is left without a sense of a limit for how many details need to be depicted in a drawing. Moreover, the learner does not receive a robust comprehension of the actual physical size of the designed space or object about its drawn image when the student initiates design with CAD tools. The purpose here is to increase the immersion into the learner's design and raise awareness between macro and micro views. In architectural design, representations, for example, with CAD, only simulate the proportional relations of the design solution but do not deliver a first-person experience (Dorta,2016). This thesis argues that the old standing concept of scale can further evolve when applying notions of immersion.

According to Sherman and Craig (2009; 2018), the term *immersion* can be used in the following ways: mental immersion and physical (or sensory) immersion. In the literature of most media, the term "being immersed" generally refers to an emotional or mental state, a feeling of being involved in an experience.

In Mixed Reality, the term is associated with physical immersion since the Mixed Reality system converges with the physical environment and stimulates the user's senses.

The state of *mental immersion* is a cognitive state of being engaged in a situation or an environment that refers to a suspension of disbelief and mental involvement. Also, mental immersion is the cognitive goal of most creators and artists of design, as mentioned in one of the definitions about immersion (Sherman and Craig, 2003)[7]. The term of mental immersion is related to the "sense of presence" in an environment of an evoked reality (Pillai,2013).

Finally, the state of *physical immersion* refers to the body of the user when entering an immersive environment. It is an artificial stimulus of the senses with technological media. Physical immersion does not necessarily employ all senses or the entire body participation. Physical immersion is created with MR tools (Sherman and Craig, 2003).

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[7] *Mental Immersion—An overview | ScienceDirect Topics*. (2003). Retrieved 8 October 2021, from https://www-sciencedirect-com.proxybib-pp.cnam.fr/topics/computer-science/mental-immersion

The concept of scale is what adds levels of immersion (mental and physical). Many different scales exist in the architectural learning process; however, immersion is perceived as one experience.

We continue by analyzing the three-dimensional models of Mixed Reality media.

2.2.2. Three-dimensional models

Three-dimensional representations or models allow designers to see spatial aspects of the existing and suggested built environments. Since the Renaissance, the practice of producing physical models of new buildings and architectural projects has been an essential accompaniment to drawings. Whyte mentions that the renaissance architect Brunelleschi first presented a chapel model in Florence to the project clients (Vasari, 1568). Moreover, Whyte (2002) informed us that the architect Wotton (1624) claimed building should not be allowed based merely on the paper drawings such as the plan and the perspective by the seventeenth century. Instead, architects and clients should see a model of the whole structural endeavour at a scale as large as possible.

In recent times, the use of 3D models supports collaborative design work instead of simply presenting the final architectural design. 3D models have been prompted by a desire to increase public participation and common sense in objective reality (Lawrence, 1987).

Models are often categorised as physical models (real) and computer models (digital). However, screen technologies present a two-dimensional environment for representation, and thus computer models are essentially representations (Whyte, 2002). The 3D models viewed on 2D screens are perceived as three-dimensional (perspective, axonometric, isometric) representations. Representations that show three spatial dimensions projected onto a 2D plane have been described as 2½D (Whyte, 2002). There are technological tools that have emerged to design in 3D space directly (such as 3D pens). However, understanding the different qualities of 2D, $2^{1/2}$D, and 3D space is a key factor in becoming an architect-engineer.

Thus, in Mixed Reality media such as VR and AR , the description of representations as models refer to $2^{1/2}$D representations (Whyte, 2002).

There are three categories of models: static, dynamic and interactive. Static models include physical and digital 3D models in traditional CAD software that can be seen from many different viewpoints (however, these viewpoints can be scaled dynamically). Dynamic models change with time and can be observed in films and computer animations. Interactive models are computer-generated and can be found in VR, AR and video games.

Static physical models (maquettes) are constructed at different scales. Perceiving the entire 3D environment for design from one viewpoint (bird's eye view) may offer a cognitive advantage. The ability to cognitively link the model in scale and the actual space seems essential to humans (Whyte, 2002).

Several designers and managers in construction companies argue that scale is irrelevant in digital models. The scale principle is considered old since design can now be produced virtually at full scale, a scale of 1:1 (Whyte, 2002). However, the designing dimensions used in 3D modelling are different from those used when viewing the model. The 3D model can be viewed in its entirety on the computer screen. It is easy to "zoom in" and "zoom out" of the model without involving any alteration of the scale of the drawing and the dimensions of the architectural object. The scale at which the designer sees the model on the computer screen is not specific (e.g., 1:100, 1:200, etc.) and, hence, unknown to the designer.

2.2.3. Viewing Perspectives and Navigation Modes in IVEs

Many types of representation are possible in mixed reality media. Whyte (2002) considers different viewing perspectives and navigational modes within immersive and non-immersive virtual environments. Whyte (2002) describes three different types of views in relation to navigation:

1) *Centre-viewers* (egocentric) — the learner experiences the virtual environment from a perspective point of view similar to how we perceive the real world. Borrowing the terminology from video games, this can be described as a First-Person Controller (FPC) view.

2) *Centred on an object within the model* (exocentric) — The point of view can be directed at a virtual entity within the world; we obtain a Third-Person perspective view. The user perceives a virtual actor or an avatar and navigates the virtual environment by maintaining visual contact with the virtual actor.

3) *Outside of the model and centred on the model itself* (exocentric) — the user becomes an external observer that manipulates the world from a static viewpoint. We call it bird's eye view.

There are limitations to the viewpoints that we can obtain in the real world. In Mixed Reality systems (VR/AR and natural environment), the view is combined with real images, and this means that it is mainly possible to gain viewer-centred perspectives on the virtual model. However, in Mixed Reality applications, we can obtain all the above possible views simultaneously.

2.3. Immersive Virtual Environments

The art of cinema and special effects, video games with programmed shaders and computer graphics changed the way architects perceive representations, design, and understand space. Virtual reality immersive environments present an increasing interest nowadays for researchers, designers, artists, and architects due to the established visual production of photography, cinema, video art, video games, medical conducted approaches, and other disciplines related to digital simulation. The culture of the "image" and the "animated form" has influenced the architectural perception significantly through the notion of "inhabiting the unbuilt" and the shaping of vivid representations of reality; thus, impacting the apprehension of the training process of architects on a cognitive level.

Investigating immersive virtual environments (IVEs), digital applications, immersive systems or installations, and their design is helpful to identify relationships between digital creation and architecture. IVEs represent three-dimensional environments, where world-building is often around cities where learners evolve and interact. Like cinema, paintings or video games, IVEs can refer to real or imaginary territories equally. Thus, IVEs can reform the perception of an actual location or a place. These digital tools offer new ways of thinking, constructing and visioning the city. This research considers appropriate digital environments for architectural design, such as the **Immersive Virtual environments** (Marchand, 2018) and their possible implications in architectural education.

Immersive Virtual Environments (IVEs) have become apparent in architectural design since 3D modelling is an indispensable spatial conception stage. The arrival of 3D modelling software such as AutoCAD, 3Ds Max, Rhinoceros, SketchUp, ArchiCAD, Revit facilitate the designing process since perspective and axonometric views have become automated viewports. However, these programs (software) do not necessarily promote spatial perception for the learner of architecture. Architectural students can utilize 3D models to simulate virtual environments that accommodate different scenarios of inhabitation. Moreover, the learners can obtain 1:1 scale immersion into their suggested designs.

The passage from 2D to 3D media representations as more meaningful representations reveals the potentials and the possibilities of 3D modelling for architectural students. The learners can transform 3D digital architectural models into places of interaction in an IVE.

The creation of potentialities also challenges is due to the ill-defined introduction of computers as a substitute for design.

However, it is impossible to synthesize analytical components simply by 3D modelling and drawing, but the approach has to be derived from holistically studies that look at interactions. Their enterprise is informatics development; it is not science. (Laudrillard, 2002). Informatics is not science, architecture either.

Immersive Virtual Environments provide an environment of immersion and interaction for architectural students. The immersion can vary according to the means employed, such as smartphones, cameras and projectors. An immersive environment is an environment of absorption, where "reality", in terms of visual and cognitive perception, is covered by digital layering and clothing. Finally, the IVEs promote more the implication of the designer's body, emotions and engagement during the design process.

In this research, we focus on the potentialities that the IVEs of Augmented Reality offers. In the next section, we present an introductory session about AR's characteristics, philosophical questions, and scepticism that arise concerning the use of this medium.

2.4. Augmented Reality

Augmented Reality refers to the effect produced by the increase of information of a real-world environment through technology, with the superposition of digital space in the real world. The additional information may include graphics, 2D images, 3D models, audio, GPS location and adds perspective for the user forming an enriched digital environment (Salmon & Nyhan, 2013). AR interfaces require interaction from the user to see its effect usually by smartphone, tablet or glasses. Milgram’s Reality-Virtuality continuum places AR between the physical environment and an entirely virtual environment to a spectrum called mediated reality.

"The digital augmented content interacts with the user actions as most of the time the AR content is tactile and quite responsive to user's input" (Loumos, Kargas, & Varoutas, 2018).

*Augmented reality is a vision for the near future that will require, if it is to happen, a detailed understanding of brain processes and brain-machine interfaces. It might take the form of direct wireless connection of the human brain to the Internet or virtual reality devices, such as virtual reality glasse*s (Buechner, 2011).

The idea of AR has existed for more than forty years and has had many uses in industry, tourism, entertainment, education, cultural heritage organizations and military operations in urban terrain for skills training (Salmon & Nyhan, 2013). Furht in the *Handbook of Augmented Reality* presents applications in several domains such as environmental planning, medical training, designing, and mobile AR games such as AR sightseeing applications of Berlin with displayed 3D graphics that have been developed from 1940 to 2008 (Salmon & Nyhan, 2013).

Museums and cultural heritage institutions use AR to visualize history and to guide people through an evolutionary past, including 3D/2D models and animations. Many examples of AR applications have been implemented and classified, as the history of merging virtual objects with reality, is longstanding.

Despite AR's long existence, it is unclear if there is a mere definition, due to the fact that AR is still evolving and being explored each year, with new displays. R.T. Azuma, a pioneer in AR development, states that an AR system must have the following three characteristics:

1) combine the real and the virtual,

2) be interactive in real time, and

3) register in 3D (Azuma, 1997) (Salmon & Nyhan, 2013).

Eric Klopfer describes AR as a *location-based* experience with handhelds and smartphones that give "additional virtual data at given locations" (Jenkins, 2008). The term of AR stems from Webster's definition of augment: "to make larger; enlarge in size or extent; increase". With AR, we are typically *increasing* the amount of information available to the user in comparison to their normal perception. However, there are cases where the "augmentation" is the digital removal of real-world information to reduce the complexity of the scene.

In this research we conclude in this definition about AR:

AR can be a system, a medium or an effect in which real-time interactive digital information is superimposed on the physical environment to increase or replace it while at the same time registering (recording) any interaction.

Finally, the main characteristics of AR that concern architectural learning is a) layered superimposition b) on-site design, and c) digital augmentation of workspace for designers.

2.4.1. Challenges in AR

The basic tool of AR media is the AR camera, a script that transforms almost any camera of smartphones and tablets into an AR tool. This is how we obtain the superimposition of the digital and real environment in the digital interface. However, several challenges arise, such as (Kipper & Rampolla, 2013):

- The Occlusion effect which refers to the obstruction of view. Often, this phenomenon affects objects that appear in depth.
- Unfocused camera: an unfocused lens system can cause the marker details to be understood with lower exactitude, that ends up in errors in positioning of the virtual object or complete non-recognition of the marker (Accuracy).
- Blurry movement or Motion blur is the visual phenomenon of streaks that appear to moving objects at speed. In AR, the impact of motion blur sometimes does not originate with the object but with the camera, sometimes on a mobile device.
- Uneven lighting: will obscure a marker by darkening parts in shadow, making it unrecognisable or recognized as a distinct marker to the AR application. The same happens if the daylight is too intense, it prevents the users from maintain clear view with the digital content.

Recognition methods for interaction with AR

Recognition is essentially the process by which the hardware and the software determine where and how to augment reality, and different digital devices will use different methods. But regardless of the type of device we utilize to interact with AR, we employ one of these four methods, which are:

- Pattern (design, textures, structural).
- Outline (shapes, geometries, forms).

- Location (GPS).
- Surface (vertical and horizontal surfaces).

a. Interaction in AR applications (see: Chapter 3.1, for further information).
    - Tangible AR interface
    - Collaborative AR interface
    - Hybrid AR interface
    - Multimodal interface

b. Display Technology
    - Mobile handheld displays
    - Video spatial displays and Spatial Augmented Reality
    - Wearable displays

In addition, some commercial applications, such as Modelo.io[8], React Native app[9], Vuforia, and other Kits[10], can help the development of AR applications for architects. These digital packages can offer a dive into an architect's sketch or augment a completed 3D model in a specific location. Henceforth, the lack of immersive digital tools for architectural education and spatial research is apparent, combined with a collaborative problem among the different disciplines. During this research, the field of AR is growing on almost a daily basis with the arrival of new devices (e.g., glasses), software and updates. The researchers cannot run behind the development of big companies. If this is the case, then the academic research about such a field can become soon obsolete since the industry dictates the changes, the challenges and the limitations.

[8] *Modelo | Best Collaboration & Design Review Software for Architects*. (n.d.). Retrieved 13 October 2021, from https://modelo.io/

[9] *How to Build an Augmented Reality App with React Native*. (n.d.). Retrieved 13 October 2021, from http://applikeysolutions.com/blog/how-to-build-an-augmented-reality-app-with-react-native

[10] *Augmented Reality*. (n.d.). Apple Developer. Retrieved 13 October 2021, from https://developer.apple.com/augmented-reality/

It is a challenge for researchers and professors in architecture to collaborate with developers to design an AR application serving young architects' education and raising awareness about various digital means.

2.4.2. Reality augmentations

The concept of reality augmentations focuses more on the notion of "reality" and "augmentations" in the plural, signifying the digital realm's multiple instances. According to this theory, reality is seen *"as the sensory and cognitive world that we inhabit"* (Buechner, 2011).

Buechner continues, "*augmented reality consists of any change in the totality of our sensory and cognitive experiences (at any given moment) that is produced by some form of technology*". Reality augmentations refer to fictional beings (e.g., virtual actors, holograms) that are or soon can be technologically achievable. The limitations from this point of view concern the concept of Reality and not the physical world's boundaries. The idea of reality augmentation meets some constraints derived from the philosophical theory of fictional or technological enhanced entities. For example, the increased use of machines, calculators, rulers, computers augmented "our arithmetical skills", but it is not considered a reality augmentation. Setting metrics is not to extend or quantify Reality in terms of "augmentations".

- Some reality augmentations can be perceived as enhancements, e.g., Headphones.
- Some reality augmentations can be perceived as therapeutic engines, e.g., Hearing aids.

Augmented and Virtual Reality can be nowadays technologically and economically supported. However, the problems that we meet are also philosophical. This issue arises if we accept "reality" as the situation where all is included. However, by definition, 'augmented' or 'virtual' Reality presents an oxymoron, since if Reality includes everything, how can it be 'augmented'? As Jeff Buechner mentions in his article, *Fictional Entities and Augmented Reality,* there is *"a fundamental problem in pure philosophy: fictional entities and how we refer to the non-existent*" [11] as he argues that some *"forms of augmented reality that are*

[11] Logic of non-existence, Saul Kripke (Heim, 1993)

metaphysically impossible and that believing that such forms are possible (both metaphysically and physically) creates a form of scepticism" (Buechner, 2011). Buechner distinguishes the fictional entities and the logic of non-existence that aspire to the 'virtual objects'. He suggests *"different kinds of reality augmentations, some of which are philosophically incoherent and some of which are not".* Buechner defined AR as a "*detailed understanding of the brain processes and brain-interfaces*", emphasising the Human-Computer Interaction and the implication of a neuroscientific approach in developing future technologies.

2.4.3. Scepticism about AR

We identified second thoughts about the usage of AR in architectural education, which are general thoughts related to AR. The first issue concerns the technical and economical maintenance in the long-term for the use and development of such applications. The second issue is cultural and operational, as these media are constantly developing, which means that AR can facilitate the learning process of tutors and students globally (Loumos et al., 2018).

In addition, VR, AR and CAVEs technologies represent the transitional period of emerging media. The existing digital tools, technologies and algorithms are evolving rapidly, permitting more data to be processed and new features to be added. This evolution refers equally to technological equipment (hardware), such as AR glasses, algorithms and the informatic languages that assist the development of digital applications.

Furthermore, the cost acquisition of special equipment (such as smartphones, smartwatches, tablets) is being reduced and leading to forecast that AR/VR spectacles will cost as much as a regular pair of glasses. (Loumos et al., 2018).

To many researchers (developers, artists, gamers), the Mixed Reality study presents a topic to "invest" as a rational choice of the increasing industrial support by colossal companies such as Google, Apple and Facebook. Several enterprises have invested and continue to invest in the development of VR/AR applications. However, the author genuinely believes that collaboration, communication and on-site visualization that are the main qualities emerging from AR applications, can improve the design activities. It is a powerful tool that demands good usage. Finally, the Academy should not fall behind the curve and, in the future to be obliged to blindly adopt AR media in the process of teaching.

Summary

This chapter was a general introduction to the main aspects of Mixed Reality. We presented a brief history about the origin of the medium of Virtual Reality and its main characteristics: immersion, interaction, navigation in first-person mode view that apt to the architectural education. The mixture of technologies can transform the architectural 3D models into interactive environments for exploration and discovery during the learning process of the Design Studio. Furthermore, we focused on the IVEs provided by AR technology. We provided several definitions of AR, also scepticism that emerge from these notions.

In the next chapter, we investigate systems and applications of Mixed Realities, both VR and AR, designed to assist the teaching of architecture.

Chapter 3: Mixed Realities in architectural education

This chapter focuses on VR and AR applications, specifically in architecture and the design studio. Both VR and AR offer different representations and applications and can be integrated into the future of architectural design studies. VR and AR applications in architecture describe the possibility of supporting immersive design, visualise 3D models on-site, and enriching collaboration.

Schnabel, Wang, Seichter and Kvan (2007) provided a classification of seven types of realities (Fig.10), including VR and AR, demonstrating how the merge of these realities can impact urban and architectural design in relation to interactions with physical objects and artefacts.

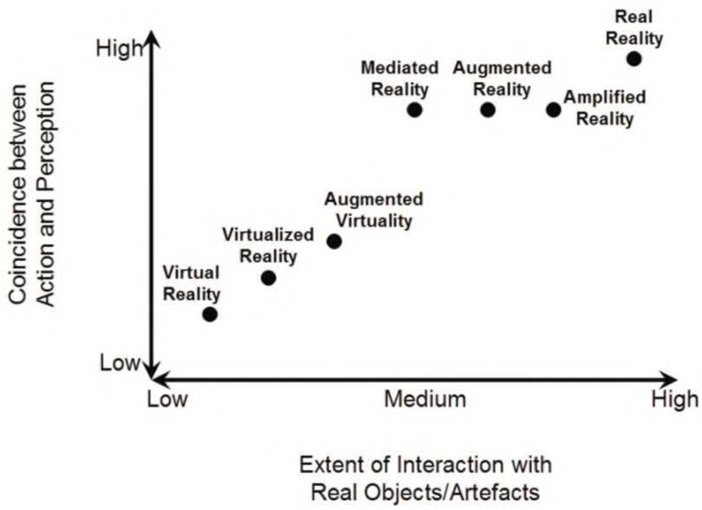

Figure 10. Classification of reality concepts according to correlation between perception and action and level of interaction, Schnabel et al., 2007.

Furthermore, in the diagram from caves to CAVEs (Fig. 11) provided by Pillai, Schmidt and Richir (2013), researchers in the field of Psychology present the concept of Evoked Reality which presents the human urge to evoke reality different from our Primary Reality (objective world reality). This idea includes discovery, behaviours, and cognitive alterations that we create through technological and artistic media evolution (See: Chapter 1).

The main argument for the reader to understand is that Evoked Reality, which is supported by Mixed Reality media, and thus VR and AR applications, is an illusion of reality, different from the Primary, objective or animalistic reality (Pillai et al., 2013).

We include this point of view here and not before because we attempt to provide an overall framework of these media. Therefore, Evoked Reality is a subjective reality created in one's mind. Due to the use of several media, the illusion evoked in a cognitive level is persistent during the times. The illusion remains until a new input by a new medium of perceptual stimuli (causing perceptual illusion) intervenes to affect psychological illusions (Pillai et al., 2013). The moment when an illusion is revealed is called "Break in Presence" (BIP) and results in a "Break in Reality" experience (BIR), often due to the employment of more sophisticated and advanced technological media. MR and IVEs are systems that evoke a break in Reality or Presence. The main aspect of this media is the immersion into a new visual, mental, or physical state that affects spatial perception, learning capabilities, and architectural expression.

Therefore, the examples that we present next in this document are applications or installations that first and foremost are designed to evoke visual illusions, either by perspective design, anamorphic images, mirrors, projectors and reflective surfaces. Mixed Reality media and IVEs master the art of illusion. Thus, we should be aware that architectural design can be affected in the future if these media are integrated into the academic curriculum. This parenthesis about Evoked Reality is a note from the author, as we will not further explore this approach's notions. We focus again on the IVEs provided by VR and AR applications.

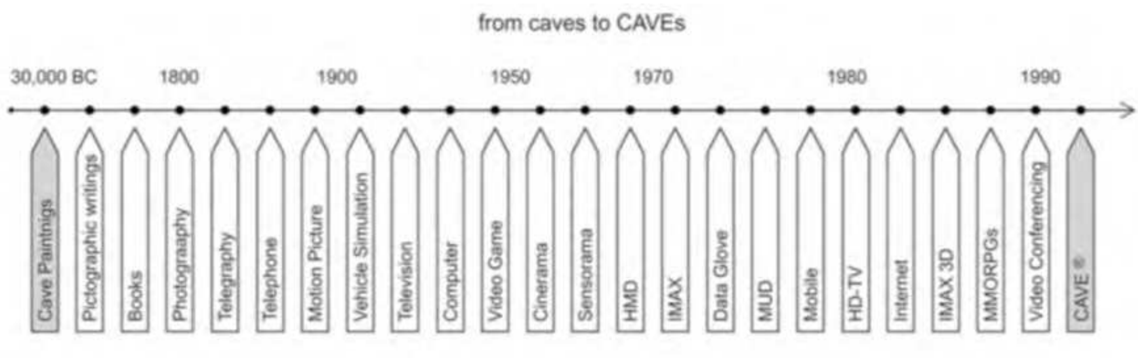

Figure 11. From caves to CAVES, Pillai et al., 2013.

3.1. Exploring the literature of MR media about architecture

Immersive virtual environments like CAVE's (Cruz-Neira et al.1992) and Panoscope[12] inspired new media forms to assist architectural and spatial education. Portman et al. (2015) focused on the use of VR in architecture, landscape architecture and urban planning, presenting the opportunities and the challenges on each discipline. Virtual reality tools can amplify landscape information through digital environments and strengthen the relationship with the user's digital presence. The modern technological media that allow the immersion and interaction in virtual and physical space can constitute a new platform for envisioning new aesthetics and experimentations in architectural studies.

Unlike more traditional media, Mixed Reality media allows participants to choose their point of view by positioning their body accordingly, allowing interaction in the virtual environment. These features (Sherman and Craig, 2018) help to make the reality more dynamic than static. The two principal characteristics of MR are immersion and interaction, as mentioned in the previous chapter (Fuchs et al., 2011). MR gives the possibility to experience First-Person view navigation in a virtual environment that simulates aspects of a real environment (Fuchs et al., 2011).

Regarding the field of architecture, the uses of MR applications are multiple, from the design itself, construction, project's communication, and collaborative decisions about design. Researchers Schnabel et al. (2001) claim that manipulating virtual environments during the design process pushes designers to perceive the fluidity, functionality, and movement inside the space better than 2D representations.

AR applications are available on portable devices, like smartphones and tablets. The portability of these devices provide an everyday medium to develop in situ applications, and that aspect can benefit designers and workers during design and construction. Wang's research (2009) on AR applications in architecture underlined the variety of user's

[12] Dorta, T. & Perez. (2006). Immersive Drafted Virtual Reality a new approach for ideation within virtual reality. *Synthetic Landscapes [Proceedings of the 25th Annual Conference of the Association for Computer-Aided Design in Architecture] Pp. 304-316*.

interactions. Moreover, the survey summarised display devices and tracking technologies for future developments.

Augmented Reality evokes a field of full potential for designers, architects, and artists, as it combines real and virtual information superimposed in one single view scene in real-time and 1:1 scale. AR allows information presented visually that the user would not be able to detect, as it reveals a reality that without smartphones, computer tablets, laptops would remain hidden. This asset of layering real and digital reality appears particularly useful for teaching architecture, building implementation, and construction learning through interaction and visual representation. Finally, perception and spatial conception are highly related to scale and immersion.

Focusing on the built environment in Architectural Research and Design[13], Kim et al. (2012) reviewed 44 articles concerning AR and architectural design, concluding to four aspects of AR applications: AR concepts, AR implementation, AR evaluation, and AR industry's adoption. Augmented Reality is a tool in the architectural conception that we research as well as the further development of this media. AR is highly beneficial for architectural students' applications, such as construction management, making tours, measuring space and interior decoration with 3D objects.

AR applications superimpose the virtual content onto the real (through the screen) environment. Moreover, the see-through applications of AR support real-time interactions and 3D registration, as it was defined by Azuma (1997) (see: Chapter 2.4).

The state-of-the-art in educational AR today is comparable to the early years of VR, meaning that many systems have been demonstrated, but few have matured beyond laboratory-based prototypes (Schnabel et al., 2007). More practical application domains of AR technology can be found in a thorough survey by Azuma (1997). Some technological problems, as

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[13] Kim, Mi Jeong,et al. "Augmented Reality Research for Architecture and Design." *Computational Design Methods and T echnologies: Applications in CAD, CAM and CAE Education,* edited by Ning Gu and Xiangyu Wang, IGI Global, 2012, pp. 225-237. http://doi:10.4018/978- 1-61350-180-1.ch013

mentioned in the previous chapter, like occlusion, motion blur and lighting result in low-resolution video capture and thus these limitations have prevented the widespread adoption of AR in various applications, including design.

AR applications can be developed based on tracking images, objects, QR codes and GPS location systems. In the domain of architecture exist systems that implement HMD (Head Mounted Display), Tangible AR, SDAR (Smart Device AR) or SAR (Spatially AR), which include the different techniques of augmenting digital content.

The daily use of smartphones and tablets, also the development of games in AR (like Pokémon GO, 2015), opened the way to support interior design, building previsualization, construction and mechanical management on the site of building's implementation.

SAR (Spatially AR) and Tangible AR offer other types of use during the design process. SAR offers the possibility to experiment on-site, on a design scale of 1:1, by displaying 3D models on the physical space, including virtual walls, floors and other objects (Raskar et al., 1998). Tangible AR (Billinghurst et al., 2008) facilitates the collaborative design and decision-making efficiency thanks to the accessibility of the design data representation. The benefit of the SAR, as opposed to AR, is that there is no intermediate display like a tablet or an HMD (Milovanovic et al., 2017).

Milovanovic et al. (2017) proposed the following six themes concerning the literature of VR and AR:

1. Applications for communication and collaboration for decision-making
2. Educative examples of dealing with pedagogical issues to implement VR or AR applications in the academic curriculum
3. Evaluation of representations based on the visualisations offered by VR and AR applications
4. Cognition-oriented approaches which place the sense of presence, the cognitive load accumulated and the simultaneous stimulation of the senses in the center of interest of the VR and AR applications
5. Immersive systems that were developed to increase and accompany the designer's creativity
6. The precise description of systems (hardware or software) for the development of applications (software architecture)

Milovanovic et al. (2017) noticed that research on applications concerning the impact on the sense of presence and cognition is more popular in VR applications than AR due to VR's higher levels of immersion. The few papers on AR that are part of that category emphasise the cognitive load decrease due to tangible interfaces, such as smartphones that transform it into a more intuitive interface to interact with the virtual world. In general, VR technology is more developed than AR (Milovanovic et al., 2017).

Tabletop tangible AR and on-site AR are brought forward for their easy-to-use characteristics and sharable quality, favouring co-design between the users. On the other hand, the use of HMD for VR is considered a limit for collaboration since the HMD is an individual device that entirely separates the user from the real environment. It also affects learners' communication because it prevents eye contact. Milovanovic et al. (2017) found that there is a lack of bibliography concerning papers that deal with pedagogical implementations of AR.

3.2. Virtual Reality Aided Design (VRAD)

Since AR technologies are less developed than VR, we kept the title VRAD as a generic field that includes AR applications in this chapter. Although AR and VR present different technologies, in this document, we present the applications together in this chapter since we could not find many AR applications that assist architectural design and education.

Donath and Regenbrecht (1995) define Virtual Reality Aided Design (VRAD) as not something new. It is described as the fundamental Computer-Aided Design (CAD) using the applications of virtual reality for human and computer communication in immersive virtual environments. This implies software and model compatibility between the different interfaces.

Moreover, 3D models imported from CAD to VRAD have to contain specific technical information and have to be modelled in purpose to be inserted in the virtual space. For example, 3D models have to be low-polygon features, contain double-face normal attributes in order to be visible in the VRAD, and also have to be exported in specific formats like .obj or fbx. In addition, Schnabel et al. (2007) mentioned that Dunston and Wang (2005) developed an AR system called Augmented Reality Computer Aided Drawing (AR CAD) for individual mechanical design details.

Fuchs, Moreau and Guitton (2011) claim while working with VRAD tools, the designers have to include more information in the 3D model in comparison to CAD tools. We claim that the information needed for designing in VR environments is not necessarily more, but indeed, the 3D models have to be designed differently, particularly concerning several conditions and behaviours attributed to the 3D models in the virtual environment (such as polygons and normal vectors of surfaces[14]). The benefit of VRAD, according to Fuchs et al. (2011), is that it can increase creativity during the design process. The difficulties in importing 3D models in a VR environment are similar to the technical challenges met in AR environments.

Despite the technical difficulties, designing directly in the Immersive Virtual Environment (IVE) has been broadly tested in many sectors such as industrial design, artistic design, entrainment, and automobile to produce a 1:1 scale prototype model. However, this practice is not yet widely developed in a Design Studio (Milovanovic et al., 2017).

Several studies on the implementation of VRAD environment were conducted to assess its potential for early design stage activity (Donath and Regenbrecht, 1999) or evaluate the impact of immersive full-scale design (Chan et al., 1999; Tresinnick et al., 2006).

Milovanovic, Moreau, Siret, and Miguet (2017) distinguished completely different display systems of immersive virtual environments. They identified IVEs that are supported by utilising a Head Mounted Display (HMD) or AR glasses, CAVEs or immersive screens for VR applications, and associated systems that blend an HMD with a screen or any surface, like tables for AR applications. Their survey (Milovanovic et al., 2017) urged six classes of systems that evoke immersive virtual environments (IVEs), and a few are tested on Design Studio academic practices. These families are:

1) VR applications with HMD
2) VR systems with the utilization of immersive screens, such as HYVE 3D and CORAULIS, as we explore further in the next section of this chapter.
3) Tangible AR, which includes applications of AR with tactile interactions

[14] The normal vector, often simply called the "normal," to a surface is a vector which is perpendicular to the surface at a given point. In a virtual environment, when the normal points towards the object's exterior, it permits the object to be visible. Weisstein, E. W. (n.d.). *Normal Vector* [Text]. Wolfram Research, Inc. Retrieved 20 October 2021, from https://mathworld.wolfram.com/NormalVector.html

4) AR applications with HMD or AR glasses
5) Smart Device AR (SDAR) or Smart AR
6) Spatially AR (SAR), together with Spatially AR Design Environment (SADRE)

There are not many relevant studies until today concerning the utilisation of VR environments during the design studio process. However, there exist many experiments and activities about this subject. Architectural students manipulate nowadays much software related to 3D modelling, 2D drawings, illustration, photorealism and rendering, skills that surpass the architectural design knowledge needed. Representation and presentations of architectural projects of DS with drawings are radically changed over the last 30 years, even less. The *synthetic image* results from the digital space, which becomes for the architect a primary 'living' place of spatial perception, design and visualisation of the architectural project that permits collaboration and communication. The virtual space is a tool that functions like a pro-thalamus before the new architecture is theoretically transferred and carried out in the real world.

Most studies about the implementation of virtual immersion in the curriculum of architecture focus on proposing new working environments, while a few studies focus on presenting educational applications. 14,5 % of articles concern AR and 16,7% related to VR about educational practices (Milovanovic et al., 2017). The majority of articles related to Mixed Reality media focus on developing systems of hardware and software design (89,1% about AR and 62,8% concerning VR). The least popular subject is cognition and senses (5,5% about AR and 34,5% about VR), according to Milovanovic et al. (2017) research.

In addition, Mottram et al. (2004) and Gül et al. (2004) highlighted behaviour's patterns during the design collaboration with and without the AR system. The sharable information displayed supported design efficiency and decision-making due to the visualisation of alternative design solutions.

3.3. Mixed Reality applications in architecture

There is an increasing interest in AR applications and architecture applied to many different aspects, from interior design to urban walks. Anders and Livingstone presented in ACADIA (2001) the Shared Transatlantic AR System (STARS) in order to create AR living rooms. Hill et al. (2010) presented the KHARMA framework, an Open KML/HTML Architecture for Mobile AR Applications.

Broschart and Zelie (2015) listed a few of the basic elements and techniques of AR. In particular, they named the described Monitor AR (MAR), the Projective AR (PAR), and the Video-See-Through (VST) or Optical-See-Through (OST). In Gül's and Halici's (2016) research MAR, stands for both Mobile and Monitor AR for marker-based AR applications.

Only a few experiments have been made in situ, in real design studio cases. Without attempting any classification of the applications, interfaces and systems, we present a few of the findings of IVEs based on our research in the field.

1) Hyve-3D

Tomas Dorta, professor at the Hybrid Lab in Montreal and his team, developed an immersive design platform, the Hybrid Ideation Space (HIS) and the HYVE-3D (Hybrid Virtual Environment–3D) to promote co-design and ideation in the VR environment. This system permits synchronous remote design collaboration (Dorta, 2007; Dorta et al., 2014).

The impact of VR during Design Studio can be significant for architectural studies. Researchers have demonstrated that designing errors in architecture are related to the "inevitable scaling" that physical objects in architecture are subject to (Dorta, 1998). Sketches, drawings, perspectives, hand-made or computer-generated representations do not correctly represent three-dimensional space and objects (Dorta, 1998)(Fig. 12).

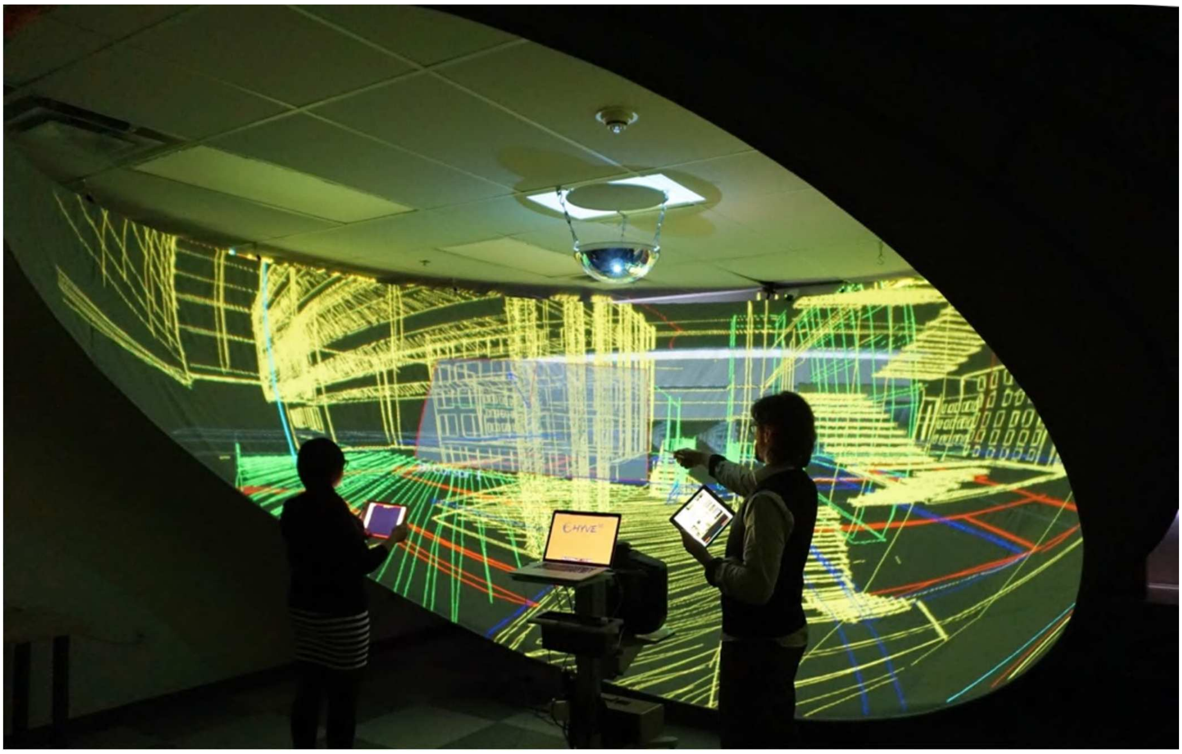


Figure 12. HYVE-3D, Experimentations in Aalborg University, 2019.

The Hyve-3D (software and installation) offers the possibility to design while being immersed inside the installation on the 360° circular screen using a tablet. The Hyve-3D software and installation (projection of anamorphic image) allow local immersive co-ideation while entirely integrating the participants inside the representational ecosystem. The system consolidates multiple representations that support co-design without interfering with the process, unlike traditional CAD tools.

Thus, students can work at different parts of the design simultaneously. Hyve-3D permits students to work on different scales (including life-sized models) with hybrid representations. The Hyve Installation is made to accommodate almost fifteen people to co-design in an active way via immersive 3D sketches, model making (using physical mock-ups) and interaction, using a 3D cursor[15] in the tablet portable device (Dorta, 2019). The projection of the anamorphic image and the 3D cursor are the innovations of this IVE (Fig. 13).

[15] Dorta T, Kinayoglu G, Hoffmann M. Hyve-3D and the 3D Cursor: Architectural co-design with freedom in Virtual Reality. International Journal of Architectural Computing, 2016, 14 (2), pp. 87-102.

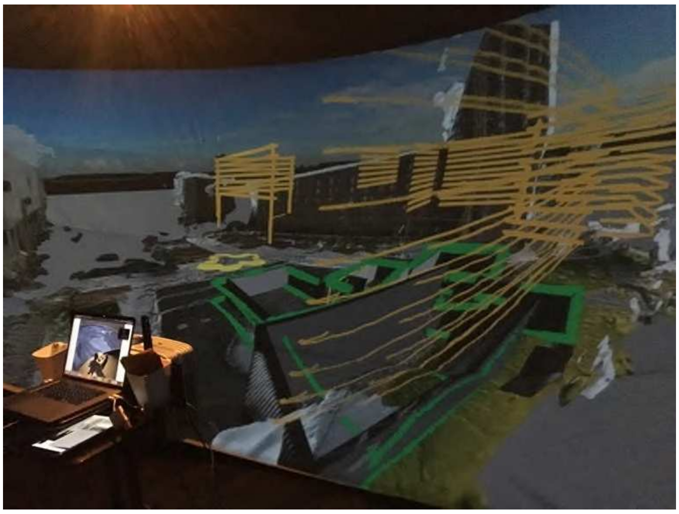
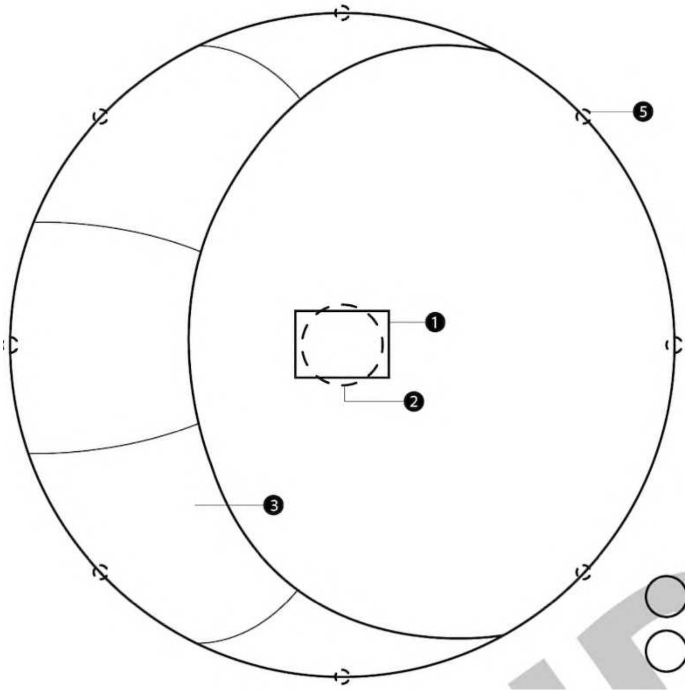


Figure 13. Designing in virtual immersion with anamorphic image, HYVE-3D.

The Hyve 3D is an immersive virtual environment that has a circular space and a projection, where designers can propose their ideas in an interactive, collaborative manner. Many experiments and workshops have used Hyve-3D. One of the benefits of this installation is that it is transportable. It weights almost 20 kilos, and the main features of the installation are presented in the Figure 14.



1. Table with a laptop and a projector
2. Optical mirror
3. Fabric screen
4. Software HYVE 3D
5. Ceiling hangers

Figure 14. Schematic plan of HYVE-3D, Source: by Tomas Dorta, 2020.

Mixed Reality installations like Hyve-3D (hybrid) and CAVES (Caves Automated Virtual Systems) host immersive experiences that can assist:

a) scale model endoscopy (miniature models and 360^{o} camera employed), and

b) collective 3D sketches (for closer observation).

This system also serves for navigation (walkthroughs), and it is compatible with 3D models extracted from traditional CAD software, also the ones that are produced from 3D scanning (point clouds). It is an advanced immersive working environment for designers. The fluidity between sketching and instant visualisation increases the user's design flow (Dorta, 2008). This environment and software, in the future, can be compatible with 3D printing. Hence, the designer will have the possibility to print the 3D model mock-up on the scale directly from the immersive environment (Safin 2020; Taouai, 2021).

2) Simulation Lab

Kalisperis et al. (2002) experimented at UPenn University with the use of an immersive virtual environment composed of a V-shaped screen to enrich the design process. Students from the second and third years of architecture tested the system for a semester (Fig. 15).

The same laboratory, named Simulation Laboratory (in short Sim Lab) was also installed in NTUA by Kallisperis in 2005. The display system is composed of screens, mirrors, back projectors and AR glasses that permit the user to obtain a vivid AR experience of the model.

The Sim Lab in NTUA is an immersive environment installation that consists of two screens measuring 3x2m each (Fig. 16), in contact with one another at an angle. Each display corresponds to a pair of headlamps connected by a stereo 3D converter (Fig. 17) that separates the signal from the computer into two images. The two images (one of each projector) are displayed in mirrors (Fig. 18) and are finally reflected on the rear surface of the screens bearing a special coating.

Two screens and four back projections assemble the immersive environment. A certain number of students have worked with Viz and a pair of AR glasses, with the RGB red-blue effect, which splits the image (red-blue) and reconstructs it in on the glasses. It is a "wearable technology" approach. Unfortunately, the lab has little been utilized in Greece.

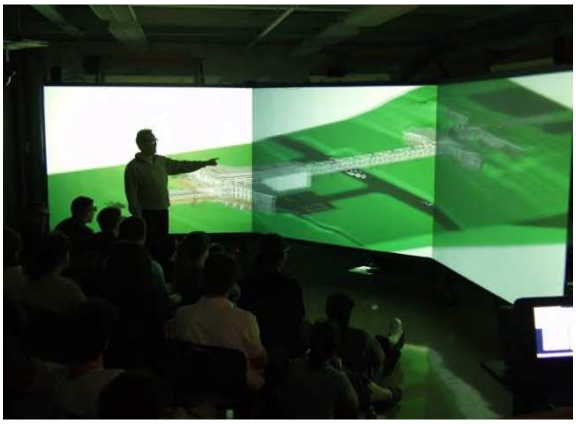


Figure 15. Architectural Course with the V-shaped AR installation.

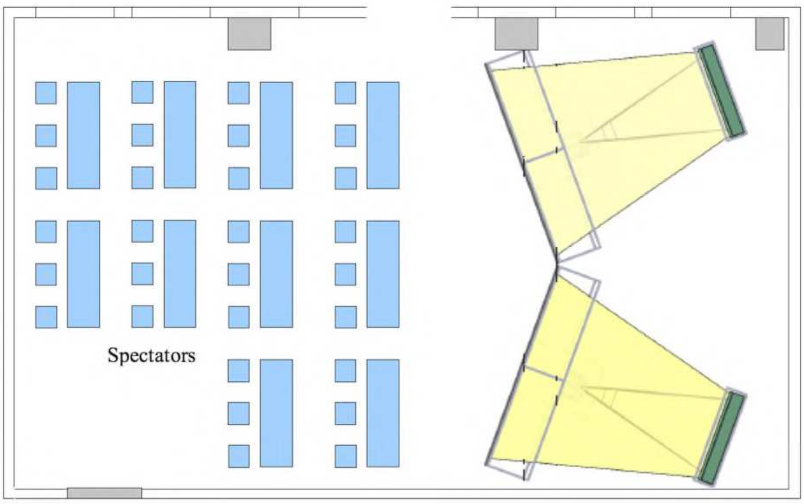


Figure 16. Simulation Lab plan diagram with two screens and back projection, NTUA

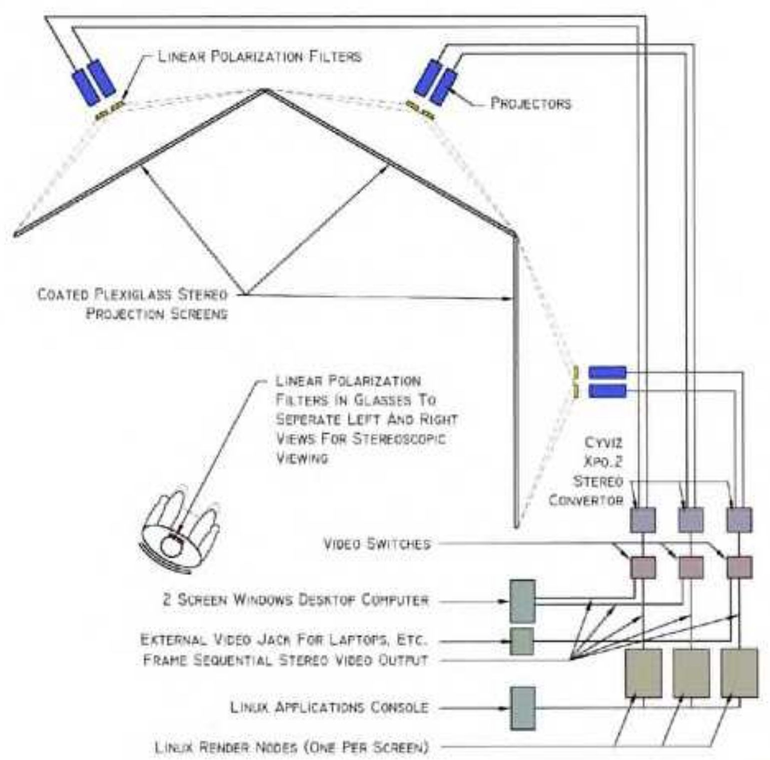


Figure 17. Plan of Lab Installation with three screens.

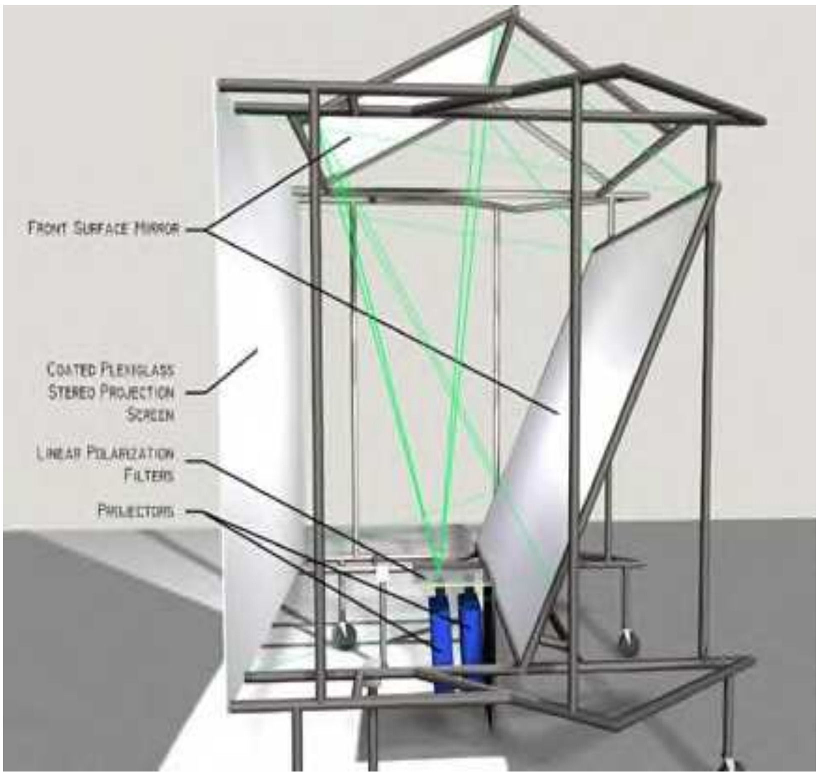


Figure 18. System with mirrors in Simulation Lab.

Source: T. Mikrou, NTUA (2018)

3) CAP VR

Architectural students tested the CAP VR system at the College of Architecture and Planning of Ball State University (Milovanovic et al., 2017). With an HMD and a large-screen projection, this immersive virtual environment served as a design environment for students of the second year (Angulo, 2015). Although at that time, the HMD was wired and could limit the free movement of the learner in the physical environment, students claimed that the immersive environment helped them during the design and enriched their projects and spatial experiences.

4) Outdoor Environment AR

Cirulis et al. (2013) suggested a 3D outdoor AR implementation for architecture and urban planning, particularly with the application *City 3D-AR*. This application combines trigonometry computations, geodesy and graphics libraries with GPS, compass, gyroscope and sensors. In addition, Andreani and Sayegh (2017) developed augmented urban experiences to reveal hidden qualities of the built environment concerning urban attractors and users' attention, urban proxemics in transportation, urban mood, spatial perception, urban vibe and dynamics. Their method was based mainly on the use of eye-tracking technologies. The researchers attempted to draw results about how people experience and inhabit urban environments based on experiments with AR applications.

5) Cultural Heritage

Archeoguide (AR-based Cultural Heritage On-site GUIDE) (Dähne and Karigiannis, 2002) presented an AR system architecture for ancient Olympia in Greece. The system displays the ruins' missing components and architectural elements in a virtual reconstruction of the historical site. The users wear AR glasses for the experience, and the system depends on a position-tracking component of the controller (Vlahakis, 2001).

Similarly, Aurasma application is suggested for an open-air tour with AR for the pyramids of Egypt (Tahoon, 2016). Finally, virtual tours with AR are possible in the archaeological site of Knossos (Crete), which reconstructs and 'adds' to the real environment digital components. It also exists graphical approaches, as in the example of Pompei. It is not impossible in the future, each archaeological location to be accompanied with the relevant AR guide application.

The sector of Culture can be impacted by the new capital and powerful digital frameworks. The example of *VA Real* can provide a typical digital instrument to enrich aspects of the cultural sector, such as the "reuse of content and end-users experience enrichment" (Loumos et al., 2018). The VAreal Web platform is a repository that collects digital masterpieces and digital cultural assets that can be visualised on virtual or physical visits by VR and AR Guide apps accordingly. The educational purposes are to raise awareness and cognition for the extended use of media and technology in historical and cultural places.

AR and VR applications (game-based logic) may help in the cultural sector and cultural heritage for reconstructing digitally monuments or parts of them that have been destroyed, for example the digital framework's reconstruction of the Notre Dame de Paris[16] (Fig.19) that was burned in 2019.

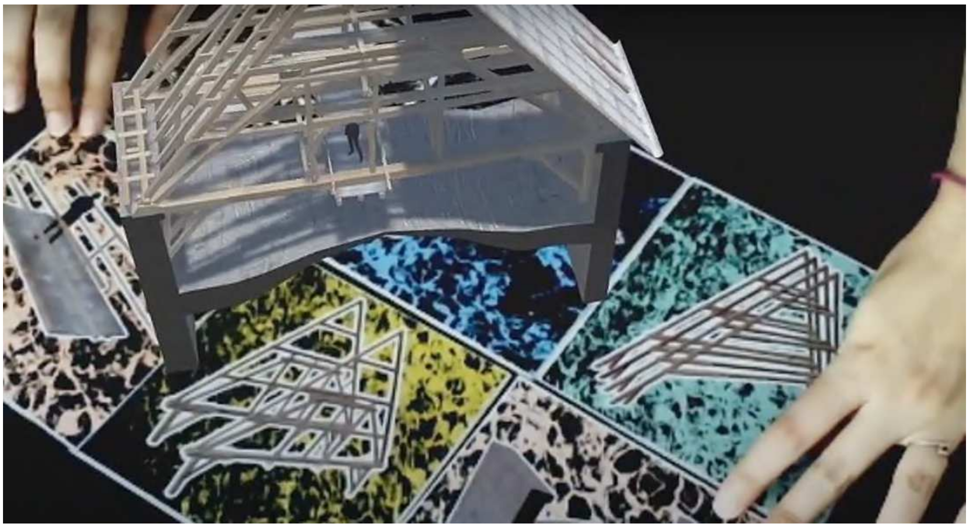


Figure 19. Application to reconstruct the elements of the disappeared framework of Notre-Dame cathedral in Paris, using an augmented reality game made on the occasion of the European Heritage Days 2021.

6) ARTHUR System – (Augmented Round Table for Architecture and Urban Planning)

Moeslund et al. (2013) presented ARTHUR, a system where the city modelled was displayed in the round table, which was perceived through a see-through HMD (Head Mounted Display), that each user had to wear. That gave the possibility to the learners to obtain a first-person view (like pedestrians) while navigating the virtual model. The users also could evoke

[16] 'Chantier scientifique Notre-dame de Paris'. https://www.notre-dame.science/ (accessed Oct. 06, 2021).

Laboratoire Map, Image retreived from: https://www.youtube.com/watch?v=WO_Okgjhr4g.

new forms and behaviours using a pointer (placeholder object–PHO). Also, a Micro-Station CAD system allowed the user to design with their natural gestures (3D pointing gesture).

7) Smart Device AR (SDAR)

The majority of AR applications utilise smart devices such as smartphones and, in the future, AR see-through glasses. Among so many acronyms, this term rather provokes confusion than clarifies any specific attributes concerning the application. The author suggests that future researchers avoid this term, as it can be easily misinterpreted instead of Spatially AR (SAR). Instead, it is more suitable to use the acronym MAR (Mobile or Monitor AR).

Gül's and Halici's (2016) study on collaborative design with MAR depicts AR applications' mobility and the benefits that can provide due to smartphone technologies, the wireless connection on the Internet, and the increasing cloud database services. Primarily, these functionalities liberated the participants from fixed locations. This study combined physical models on scale (maquettes) with the use of tracking images (markers) to augment digital content. This study is a comparative one, between 3D modelling in AR and physical modelling with cartons. The experiment demonstrated different behavior patterns during the collaborative design process in relation to the learners' media employed (analogue and digital). In particular, the researchers claimed the reduction of the designer's cognitive load during *form-finding* with the MAR application. This result was based on the finding that design ideas were generated continuously, providing alternative spatial solutions rapidly compared to the physical models.

MAR applications have been multiplied due to the commercialisation and the everyday use of smartphones and tablets. Hsu et al. (2013) identified three models of realities based on smart device AR (SDAR) indoors. The filtered reality, which is used for interior design and to place objects virtually into a room. The parallel reality, similar to the filtered, is described as a 'window' of unseen features, and it can be used to visualise an entire portion of a physical indoors space with augmented data. In the end, the projective reality consists of micro-projecting a virtual image (texture) onto surfaces of a physical environment (such as walls or tables) to observe dynamic visual effects.

MAR and SDAR systems are suitable for on-site applications indoors and outdoors. They offer the benefit of building management, construction surveillance, and a preview of future project's visualisation.

8) BenchWorks System

BenchWorks is another Immersive Virtual Environment designed to facilitate the architectural design (Fig.20). This system combines optical tracking (AR Toolkit) and magnetic tracking (Seichter, 2004). It demonstrated that tangible interaction with models is more suitable for the early stages of design. BenchWorks is a collaborative design environment system using an Olympus Eye-Trek HMD with a camera and sensor. Learners can visualise their design, generate shapes and keep notes inside the immersive virtual environment.

Figure 20. Bench Works System (Seichter, 2004).

9) CDP (Collaborative Design Platform)

Schubert and Petzold (2016) presented a Mixed Reality collaborative platform for design with AR and foam physical models (Fig. 21). This system setup combines a smart AR- device, a 3D on-top depth camera and a table. Two software were developed to implement the first CDP's prototype, as it does not utilise tracking markers. The participants can place physical 3D objects (foam mock-ups) on the table, and in parallel, they can visualise 3D models of a bigger area on the smart device (tablet). This platform is a multiuser real-time experiment that offers 3D simulations about the urban context (like wind and shadows) combining AR visualisation and physical models. CDP targets to promote design collaboration, active participation of the learners and a decision-making workspace for designers and clients.

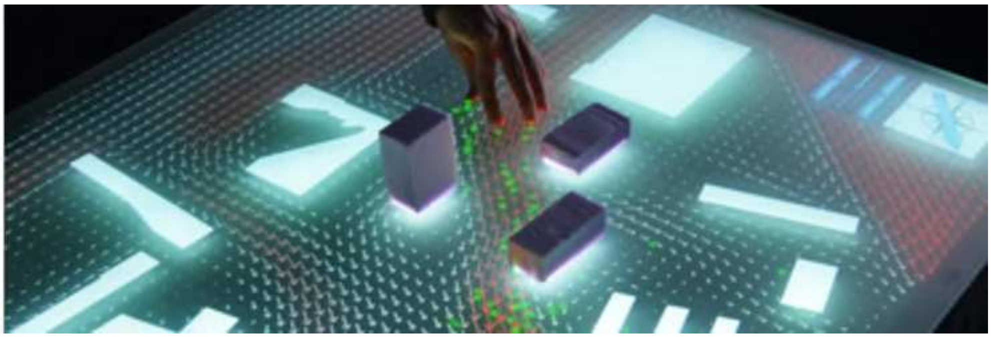


Figure 21. Tangible Mixed Reality, 2D presentation of simulation results on the table surface – seamlessly connected to the physical working models, Schubert et al. (2016).

10) Linking BIM

Wang, Kim and Park (2015) provided a conceptual framework for implementing BIM (Building Information Modeling) with AR in construction. This on-site integration aims to facilitate building management, especially for complex projects, linking physical and digital aspects of design. In addition, Vassigh et al. (2016) suggested the AR-SCOPE, which included a geo-location algorithm that aimed to enhance interdisciplinary learning by combining AR and BIM. Moreover, the researchers suggest that linking BIM and AR provides alternative possibilities of data representation that architectural students could benefit from during the learning process.

11) Interior Design AR

Abboud (2014), in the thesis "Architecture in an Age of AR", presented several examples, one of them was the New IKEA Catalog App, for superimposing IKEA furniture in a room and checking its scale inside the physical space. SDAR applications listed above (number 7) promote indoors AR applications.

12) Luminous Planning Table (LPT)

The Luminous Planning Table concept initiated by Ben-Joseph et al. (2001) aimed to support the idea of a multi-layered manipulative platform that combines physical and digital representations (Fig. 22). This was achieved by a system of cameras, video projectors, and data resources related to physical models and drawings. This type of immersive virtual environment provided simulations that merged architectural representations with environmental data such as traffic, wind, shadows and reflections.

Figure 22. The Luminous Planning Table used in a classroom, Ben-Joseph et al. (2001).

13) SARDE - (Spatial Augmented Reality Design Environment)

The SARDE system (hardware and software) implements Spatially AR (SAR) for students in interior design. Chen and Chang (2006) demonstrated that this immersive environment supported the students' design decisions on a 1:1 scale and increased their confidence during the presentation of their projects. The interface also provided textures and different materials that assisted the process of design. In addition, the system included a sensor (webcam) and a back-stage projection with a mirror. The camera analysed the gesture location of the learner, and the projector would adjust the design on the 1:1 scale of the projected image. The learner with the hand's gestures can alter the scale of the design, enabling the flow of body movements during design.

The aim was to reveal the true intentions of the designers between what they say, what they show by hand gestures and how they design. This example of an immersive virtual environment includes the body-reference behaviour of the user while the user remains free of any wearable devices.

14) CORAULIS

CORAULIS is an immersive multimodal platform and installation developed recently at the University of Architecture in Nantes, France. CORAULIS is composed of a 360^{o} screen projection. This is a mixed reality media environment since it is designed to host VR and AR immersive experiences for architectural design. The architecture of this system consists of a three-layered system concerning the virtual 3D model, which is imported by traditional CAD formats (.fbx, .obj and .skp), the visualisation of the 3D model and the interaction of the participant (interface controller) (Fig.23). This system allows the virtual immersion through the projection on the circular screen (PAR–Projective AR) and a Spatially AR (SAR) display on the table, which is placed in the center of the installation.

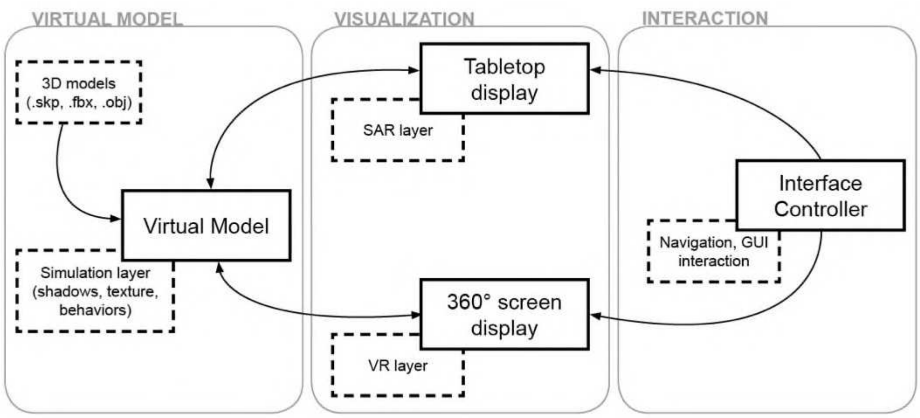


Figure 23. The system of CORAULIS, Milovanovic et al., 2017.

The SAR display is destined for the projection of 2D architectural representations such as plans, maps and sections on the table's surface (Fig. 24). Also, the same area can host 3D physical mock-ups (Milovanovic et al., 2017), such as in the CDP example we presented before. The system aims to simultaneously provide a first-person 3D view through the 360^{o} screen and top view 2D representations projected on the table of the same 3D virtual model.

Milovanovic et al. (2017) claim that the CORAULIS system is inspired by the Worlds in Miniature (WIM) metaphor, a concept introduced by Stoakley Conway and Pausch (1995). In other words, both the interior and the exterior of a building can be visualised (overall view) and be virtually visitable (first-person view) simultaneously. The coexistence of multiple immersive viewpoints of the project can be beneficial for the architectural students during several stages of conception for *form-finding* and *form-understanding*. The system is at its first stages of development, and until now, it has not been tested yet with the architectural students at the university.

The synchronisation between the SAR tabletop view and the first-person view during the navigation of the 3D model is one of the main challenges of this system to be overcome. Lastly, this system can be linked with BIM in the future.

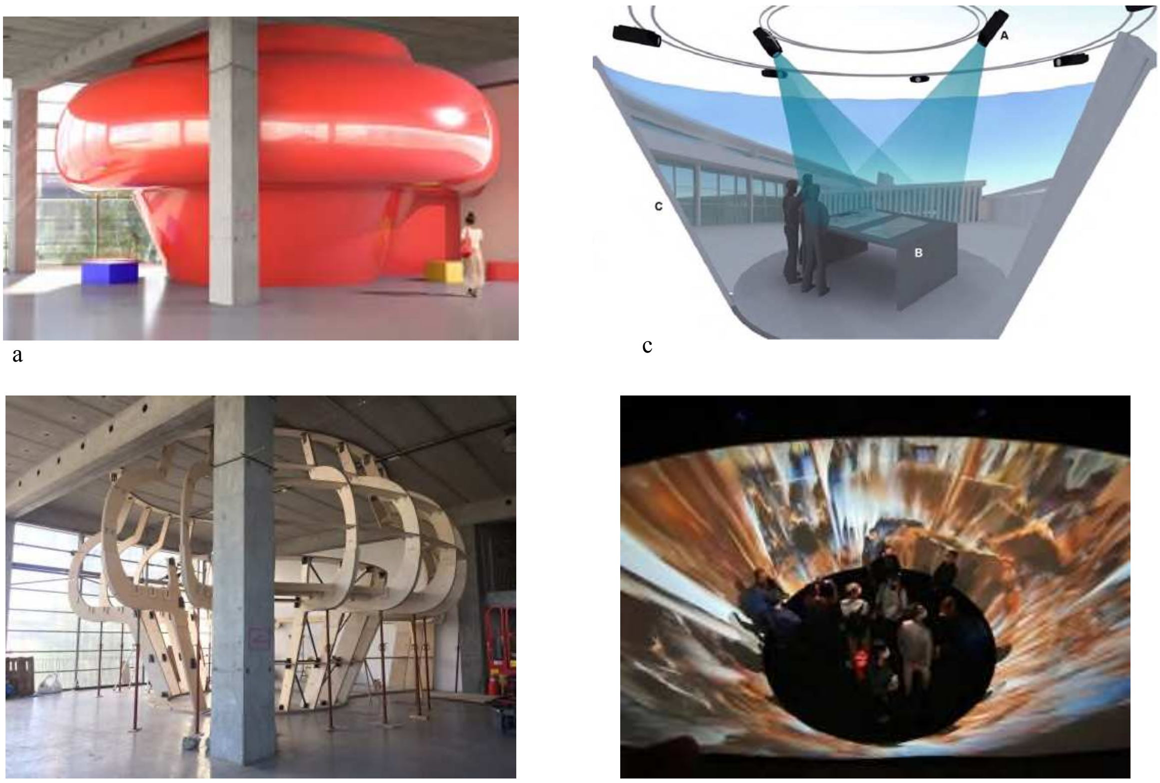


Figure 24. a) Render of CORAULIS concept, b) The construction of the immersive environment in the University of Nantes, France c) CORAULIS interior concept and, d) First tests with the immersive environment, 2021.

Images retrieved from https://aau.archi.fr/actualites/2785-from-virtual-to-physical-first-pictures-of-the-construction-of-the-coraulis-structure/ and Milovanovic et al., 2017.

15) VR Theater patents

*Notice: Subject to any disclaimer, the term of these patents is extended or adjusted under 35 USC 154b.

The author considered it useful for the reader to include also this type of IVEs. The VR theaters are designed for entertainment purposes and not for the architectural design course. However, it can be an inspiration for the development of future immersive systems. The following virtual environments are registered as United States patents applications and are listed below.

a. Interactive VR performance theater entertainment system (2002)

The inventors, Sprout et al. (2002), present an IVEs for multiple participants for entertaining and educational experiences. The system is designed to support VR devices such as HMDs. However, the participants of this system gain limited control over the content of the performance, which means that it is an immersive representational environment but provides little interactivity, and thus limited potentials for design. It can be used in the courses of history of architecture and art.

b. VR theater (2003)

The innovation of this system is that it provides a boundless immersive environment. The inventor, Thomas Hennes (2003), suggested an environment where the projection surface surrounds the participants, both horizontally and vertically, with 360° projections from the ceiling and the ground (Fig. 25).

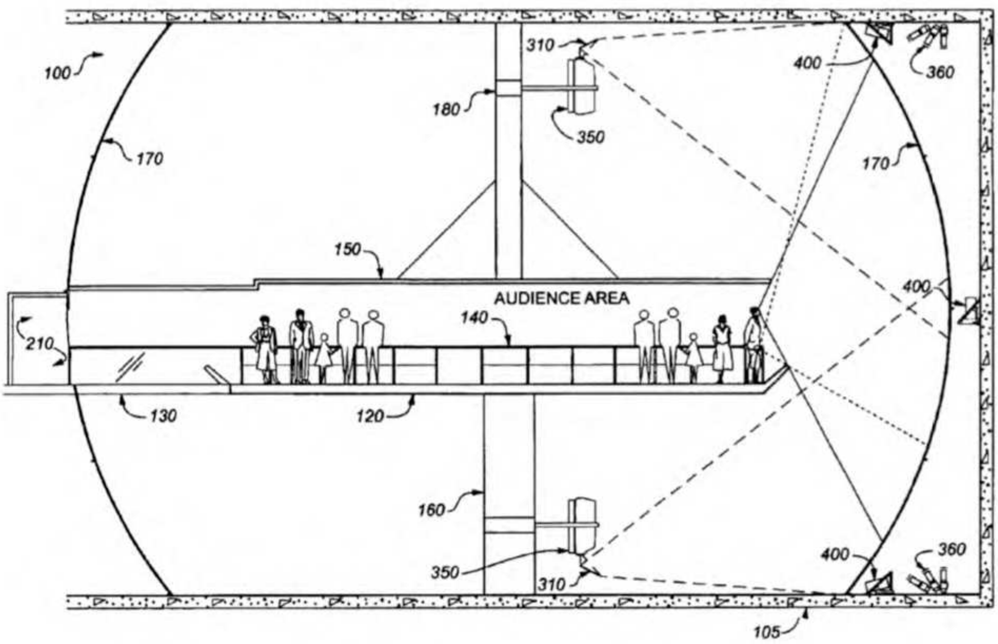


Figure 25. VR Theater section with vertical and horizontal 360 °projections, Hennes, 2003.

c. VR Dome theater (2010)

This system supports a dome-shaped screen and a reflective floor, and it is supported by mirrors and other devices such as microprocessors, speakers and LEDs lighting elements (Fig. 26). The overall structure can be circular or elliptical. The inventor, Cecil Magpuri (2010), relates cinema theaters with structures to provide sensory immersion in motion with the projections of 2D and 3D representations.

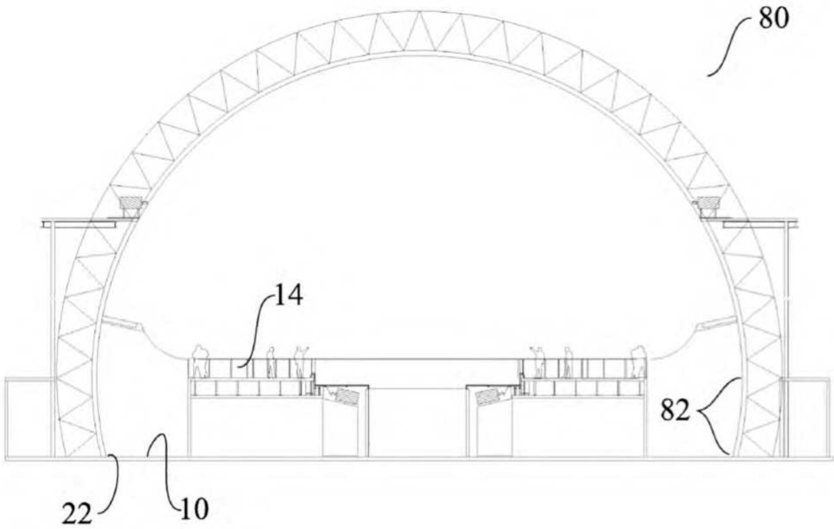


Figure 26. VR Dome Theater, Magpuri, 2010.

Summary

The listed examples can inspire future classrooms for architectural design in virtual immersion. Bodily experience is crucial for comprehending 1:1 scale design in relation to human size. Researchers are still on the quest for providing suitable IVEs, and the challenge that at least concerns architectural education is to provide a 1:1 scale projection. Often the large screens represent spaces larger than they are actually designed. In contrast, the physical models made of cartons are smaller than the architectural object. In other words, the digital enlarges architectural dimensions, while the traditional mock-ups compress the architectural dimensions.

The challenge is to produce immersive virtual systems that simulate the architectural conception accurately in terms of dimensions, proportions, analogies and materials. IVEs should be environments that promote accuracy and creativity. For this purpose, architects, developers, and experts from other disciplines should work together.

In this chapter, we investigated innovative IVEs to assist architectural education and design studio. In the next chapter, we analyze our two-semesters teaching experiences during the Design Studio course in NTUA.

Chapter 4: Analytical tools and experiences in the Design Studio

In this chapter, we present an analytical framework for spatial comprehension that is fundamental in architectural education. We describe the main issues that an architectural student face during the process of Design Studio. Furthermore, we present the teaching experiences in Design Studio and an analysis of the media employed currently in architectural studies.

4.1. Precedents of Architecture

This section presents an analysis of the major issues in architecture, placing the building as the dominant practice and idea of works of architecture. In their book, Clark and Pause *Precedents in Architecture, Analytic Diagrams, Formative Ideas, and Parts – 4th* Edition (2012) explore a selection of issues that architects face when conceiving and designing space. These issues are used as criteria from where we can extract similarities and differences to building, identify architectural styles, and this results in fundamental elements for spatial conception.

The spatial elements selected refer to the structure; natural light; massing (volumes); plan to section or elevation; circulation to use-space; unit to the whole; repetitive to unique; symmetry and balance; geometry; additive and subtractive, and hierarchy.

1. Symmetry and Balance

Symmetry and balance are fundamental concepts since the beginning of architecture. Balance occurs in architecture through spatial components to establish the building according to the law of gravity. Symmetry is a special form on both sides of balance based on the axis as the balance line. In architecture, we can obtain symmetry through rotation around a point and move along a line. Conceptual balance can be achieved when architects give additional value or meaning to an individual or group of spatial components. Size, orientation, location of the site, articulation and configuration of spaces and value are involved in formative design ideas. Symmetry and balance, the same with hierarchy and geometry, impact on other issues of architecture.

2. Unit to whole

This is a fundamental architectural issue, as units are identified entities directly related to constructing buildings. Units are spatial entities that correspond to use spaces, elements of structure, volumes or other collections of these elements. The nature, identity, expression and relation of units to another unit of a building or the whole are related aspects of the design strategy. In this analysis, units can be adjoining, overlapping, separate, or less than the whole. Structure, massing, and geometry are major factors and support balance and symmetry, hierarchy, the additive and subtractive process, and the relationship of the repetitive to the unique in relation to space.

3. Natural Light

The specific location of each place is related to natural light and how daylight enters a building. Light is a vehicle for form and space rendering and affects the perception of volumes and colours drastically. Natural light is studied more through elevations and sections of a building as often it functions as a filter, screen or reflection on a building's façade. Relevant to natural light ideas are concepts like size, location, frequency of opening, shape, surface, material, and colour. Natural light is linked to spatial elements such as geometry and structure, circulation to use-space, hierarchy, and unit relationships to the whole.

4. Circulation to use-space

Circulation and use-space represent the static and dynamic elements of architectural design. Circulation determines how users experience the built environment and use-space is the primary focus of decision making during spatial conception relative to function and movement. The space dedicated to movement can be separate from the use-spaces and it may establish entrances, centre, terminus, and points of importance. Use-space is the beneficial surface for use and it can be a free surface or open plan, and also it can be as discrete as a room.

There patterns are created by the relationship between major use-spaces. These patterns may suggest linear, central or cluster organizations.

As part of this analysis, circulation to use-space relationships reinforce concepts like structure, natural light, unit to the whole, balance, geometry, repetitive and unique components and hierarchy (Clark and Pause, 2012).

5. Plan to section or elevation

Plans, sections and elevations are orthographic drawings and representational simulations of vertical and horizontal elements of a building. The plan is considered the generator of form, a “battlefield” of decisions for spatial design ideas, and a device to organize functions, activities, and urban environments. The plan also signifies the distinction between spaces of movement and circulation and spaces for the rest of uses.

Elevation and section are considered drawings that are closely related to perception for encountering the front of a building and the development of a building in height. A combination of plans, sections and elevations are employed during the educational process; however, the use of these tools “presumes volumetric understanding” (Clark and Pause, 2012). Concepts of equality between spaces, similarity or difference and proportions can influence spatial configurations during design.

As part of this analysis, the plan to section and elevation relationships reinforce “the massing, balance, geometry, hierarchy, additive and subtractive, repetitive to unique and the relationships of the unit to the whole” (Clark and Pause, 2012).

6. Massing

Massing refers to the volumetric configuration of the building as a totality. Volumes shape three-dimensional space, and it is one dominant tool of architectural conception as it becomes a visual decision-making tool in three dimensions. The volumetric approach of buildings as a design idea is related to “concepts of context, collections and patterns of units, single and multiple masses,” and other spatial elements, primary and secondary (Clark and Pause, 2012). Finally, massing is related to issues of design and ideas as repetitive to unique, unit to the whole, plan to section, geometry, additive and subtractive, and hierarchy.

7. Geometry

Geometry is used as a design tool since the beginning of design and architecture, as it is the most common characteristic in buildings. Geometry, concerning volumes and surfaces, plane and solid geometry, embodies a determinant factor for the form of the building. It can be applied to various spatial levels such as geometric shapes, proportions, grid and complex forms generated by manipulations of geometries. A grid is a tool for architectural design, and it is identified by the repetition of the basic geometries, measurements and rhythm. A grid is related to “frequency, configuration, complexity, consistency, and variation” (Clark and Pause, 2012).

The geometry is being multiplied, combined, subdivided and manipulated by the grid. As an architectural form generator, geometry is a measurement and quantification tool which focuses on size, location, shape, form and proportion. It also includes the consistent changes and form languages of geometry as results of combination, derivation, and manipulating geometric elements. Geometry reinforces all the issues of this analysis.

8. Structure

Structure exists in all buildings as it is synonymous with support. Columns, walls and beams are all structural elements that can be perceived through concepts of frequency, pattern, simplicity, regularity, randomness and complexity (Clark and Pause, 2012). The structure uses a syntax of spatial vocabulary to define space, give dimensions, create units, organize circulation and movement, or develop the composition of spaces and modulations. There is a direct link between the creation of architecture and the quality of the structure. The latter is also related to issues such as natural light, unit to whole relationships and geometry as it reinforces the relationship with the circulation to use space and symmetry, balance and hierarchy.

9. Additive and Subtractive

Additive and subtractive are formative design ideas to create architecture by adding and subtracting build. When the additive process is applied to generate form, the parts or identifiable units of the building are emerging as dominant. On the other hand, when the subtractive process is used in the design, it results in buildings that the whole is dominant. Both processes lead to spatial consequences according to additive and subtractive considerations. As processes can co-exist, it is possible to subtract pieces or volumes (like in 3D Tetris game) from a building or an identifiable whole and add the subtracted units back to create the architectural form. Additive and subtractive design ideas may be observed in massing, volumes, materials and colours changes and reinforce the ideas of geometry, balance, hierarchy, unit to whole relationships, plan to section and repetitive to unique.

10. Repetitive to unique

In this spatial relationship, designers explore attributes for rendering formal components as multiple or singular entities. Architects focus on the conditions and attributes that make an element different or unique compared to a class of similar elements. In this analysis, components are defined as repetitive or unique through the absence or presence of several attributes. To distinguish between repetitive and unique, as they coexist in numerous ways and scales, it is useful to refer to concepts of size, orientation, shape, form, configuration, colour, material and texture. This issue generates design information that supports the concepts of structure, massing, plan related to section and elevation, units related to the whole, geometry and balance.

11. Hierarchy

Hierarchy is the physical manifestation of the ordering of an attribute or attributes. This concept embodies the assignment of relative spatial value to a range of characteristics related to space. Hierarchy implies qualitative spatial differences within a framework of an identified or selected attribute such as "major-minor, open-closed, simple-complex, public-private, sacred-profane, master-servant and group-individual" (Clark and Pause, 2012). It is important since it is used to examine design patterns, scale factors, geometry configuration and articulation. Ornament details, quality, richness and special materials are used as indicators of importance. Detailing augments the sense of immersion and presence in a specific built environment. Hierarchy is used to all the other design issues presented in this analysis.

The design issues when combined reveal the complexity of architectural design learning process, also the non-linear nature of this educational practice (Fig. 27).

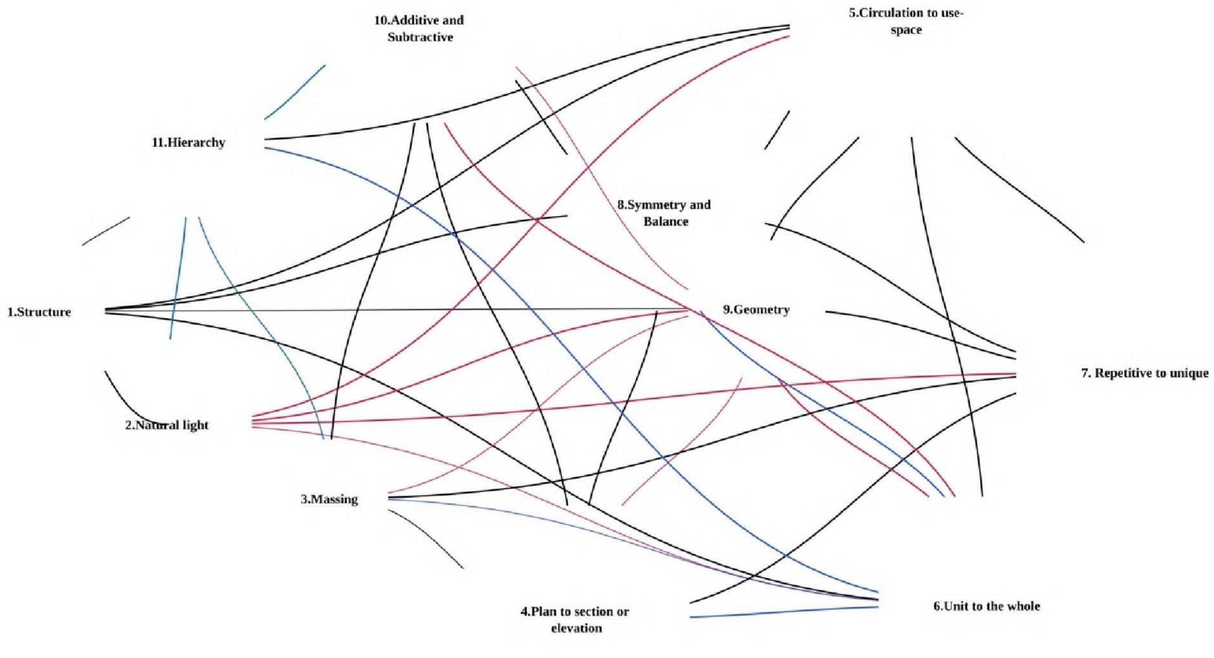


Figure 27. Mind map sketch of the author about precedents in architecture.

According to Kant's theory, forms and concepts belong to the domain of a universal subject of architectural knowledge, while materials and other objects reside in nature (Hight, 2008). Therefore, we present the colours and materials as separate issues and formative ideas of architectural design.

a) Colours

The use of coloured spatial elements can also be a formative visual idea for the building, signifying spaces and relationships between spaces. We can find several examples in architecture that use colour as a bold statement for the building, such as Tour Marseillaise designed by the architect Jean Nouvel. The architect chooses three colour combinations to cover the whole building. Many examples can be explored through the employment of different colours in architecture.

b) Materials

In this sub-section, we briefly mention the importance of the materials used for architectural design.

Each building can be considered a living organism, with structure, skin and several items and facilities that permit its function. Previously, we examined several formative ideas that architects apply to design because the matter is the means of architectural expression.

A building's structural organization depends on the use of different materials that designers have on their palette. The expression through materials, from an architectural perspective, transforms matter into space.

The use of materials is a significant formative idea during architectural conception. Such materials are glass, concrete, wood, metals, plastics and masonry (Bell, 2006). Each one has specific characteristics, types and balances differently between aesthetics and function of a building. For example, there is *lead glass*, *plate* glass, cast, a relatively soft glass, and tempered glass, considered a type of safety glass, called *toughened glass* (Bell, 2006). Several architects suggest facades made of glass, so the material becomes the skin between exterior and interior. Materials are the tools to define structure, geometry, balance and natural light. The mastering of each material use according to design is one of the main educational purposes of architectural studies. Another type of materials is the-called "smart materials", towards a more "sensorial" architecture (temperature, movement detection, pressure, recognition, light).

The ultimate task of architecture is to act in favour of man: to interpose itself between man and the natural environment in which he finds himself, in such a way as to remove the gross environmental load from his shoulders[17]. This phrase is credited to Marston Fitch, *American Building 2: The Environmental Forces That Shape It* (1972) in Janković's slides.

The analysis of smart materials subject is not exhaustive in this thesis since it is a huge subject that combines other disciplines. However, VR and AR devices can be very beneficial for simulated smart materials in the future.

The following section provides a brief description of the Design Studio course during the five years of architectural studies.

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[17] Janković, V. (2016). *What do we talk about when we talk about climate (slides)*. Retrieved 20 October 2021, from https://www.academia.edu/52624275/What_do_we_talk_about_when_we_talk_about_climate_slides_
The slides are from the Haymann Rooke Memorial Lecture at the University of Nottingham in 2016.

4.2. Design Studio across the academic years in NTUA

According to the NTUA curriculum, students attend nine major architectural Design Studios during the five year course of studies in architecture. The learning experience of Design Studio is fundamental for becoming an architect.

- First Year

During the first year, the architectural exercise focuses on observing the surroundings and the city's *natural* and *artificial* landscape. The learning process is still individual, as it moves from primary and secondary education into the academic medium of tertiary education.

The first semester initiates the student in three types of architectural design exercises: i) guiding the eye in the built environment, each student selects a street in the city and analyses its architectural characteristics (e.g., symmetry, proportions, uses, etc.), ii) further, the student explores the transformation of a cube (30cm edge) with six moves (cut and paste in 3D) as additive and subtractive process, and iii) finally, the student designs and models an imaginary route in given proportions of a rectangular box (10m*10m *25 m). As we transfer to the second semester, the Design Studio process is still an individual exercise. The student is asked to deliver a small building construction, such as a restaurant or cafe in the natural environment (not urban). The emphasis is on design as the science of organisation and design as a system (moves, observations, decisions).

- Second Year

During the second year of architecture, students can form groups composed of two to three people for the semester's final project. The second year is dedicated to obtaining knowledge about housing buildings such as apartments, social housing, complex houses, residencies and villas. This period is crucial for developing educational practices in groups, which follow in subsequent years, as students are initiated into housing principles and modelling in a certain urban environment.

- Third year

In the third year, the exercise of architectural design studio (for the fifth semester) includes the design of a building with a public role, e.g., a school, a library, a museum, a hospital, integrated into the urban environment. In the second semester of this academic year (sixth semester), the design studio exercise focuses on implementing buildings or complex of buildings in a natural landscape (outside the metropolis).

- Fourth year

The fourth year is a particular design transdisciplinary practice since two different departments of the Architectural School cooperate, the Department of Design of Space (Department 1) or the Department of Architectural Language, Communication and Design (Department 3) with the Department of Construction Technological Edge (Department 4), for the entire academic year. The same subject lasts the whole academic year (both semesters). Usually, the given subject is a public building such as a museum, library, art centre, a theatre to be integrated into the urban environment. The students have to design and organise some thousands of square meters on a 1:50 scale while advancing with structural and technical drawings on 1:20 and 1:5 scale.

- Fifth year

The ninth semester is dedicated to designing a large housing project in the urban fabric and work on scales from 1:5000 to 1:200 and occasionally 1:100.

Lastly, it follows the Diploma project, where students choose their subject to analyse and eventually make architectural design suggestions for sites for building implementation and landscape.

4.3. Design Studio teaching experience

We present the experiences during two semesters of Design Studios auxiliary work, from the fifth (2018) and fourth (2021) year of Master's students in architecture (NTUA). Thirteen years ago (2008), the author was an architectural student completing the Masters in the fourth year and fifth year of architecture and took these courses from where the interest in architecture and representation began.

During Design Studio, several methods co-exist in the educational process. For example, some designers start to conceive space from the interior towards the exterior, while others began the architectural idea from the exterior form towards the interior arrangement.

In addition, there are software and practices that focus on developing communication and learning while others focus on design.

The two subjects we explored during this research regarding teaching architectural design for two semesters refer to the planning of a Social Housing project (2018-2019) and the design of an Art Hub Centre (2020-2021) in the city of Athens, in Greece.

During the winter semester of the academic year 2018-2019, the DS courses were entirely held in the studios with the physical presence of the students and professors. The process followed the traditional norm. During the winter semester of the academic year 2020-2021, the DS courses were entirely held online with the digital presence of the students and professors (due to the Covid-19 sanitary crisis). As the subject of this thesis is to suggest hybrid methods of teaching architectural design, combining traditional and Mixed Reality digital methods, we found suitable to compare the two experiences, in terms of the digital media employed in both situations.

4.3.1. Digital media use in the design studio teaching experience

- Design studio Social Housing 2018-2019

During Design Studio held in 2018, assisting the work of professors Mattheos Papavasileiou and Stavros Stavrides, the learning process included the physical presence of students (Fig. 28). The digital part of education concerned blogging to communicate and being notified about useful information for the course. Cloud storage services, such as Dropbox, were employed to exchange large files, maps, drawings, and other documents. Furthermore, we explored software and plug-ins for design such as Isovist, Grasshopper and 3D printing in some cases.

To complete the ninth semester Social Residence methodology, the student groups design a residential typology to accommodate the housing scenario chosen by the students, on a scale of 1:100. Several differences in size perception and transition in varying scales present a cognitive difficulty of the specific exercise. The student is asked to use a combination of knowledge and complexity.

During this semester, we launch a questionnaire to the architectural students about their difficulties during the DS, also their opinions about the integration of VR and AR during their learning process. We present the results in this chapter (see: Chapter 4.3.3).

In addition, we managed to develop a mixed reality technique with virtual actors (Velaora et al. 2019[18]), which we present later in Chapter 8 (Educational model 3).

Figure 28. Corrections and critic sessions during the Design Studio in NTUA, 2018.

- Design studio Art Centre 2020-2021

During Design Studio held in 2020, assisting the work of professors Nicholas Anastasopoulos and Panagiotis Vasilatos, due to the sanitary crisis of Covid-19, the educational process was transferred online as the physical presence of tutors and students was not permitted. The second time that I assisted as a tutor in Design Studio was an interesting experience since, due to special conditions, the course had to be held entirely online. During this period, the courses were assured digitally. Several platforms emerged, such as WebEx, Zoom, Teams and Google Meet, in order to ensure the regular flow of architectural design studios (Fig. 29). In addition, applications like Miro were employed, a digital whiteboard where students can pin presentations and be visible and accessible to tutors and other colleagues.

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[18] Velaora, M., Guéna, F., Moraitis, K., & Papavasileiou, M. (2019). Integrating Digital Reality into architectural education. *Steinø, N., & Kraus, M. (Eds.) (2019). Virtually Real. Immersing into the Unbuilt: Proceedings of the 7th ECAADe International Regional Symposium. Aalborg Universitetsforlag.*, 11.

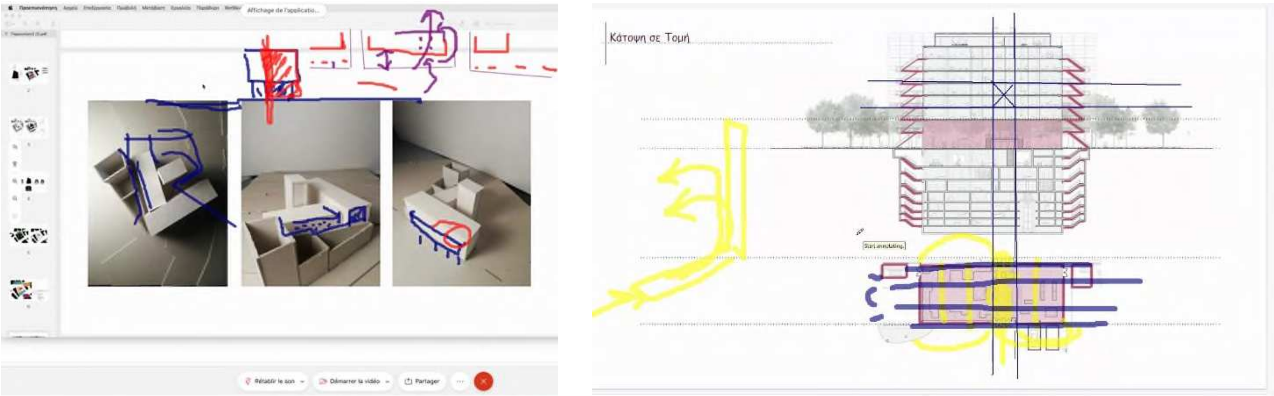


Figure 29. Corrections during the Design Studio, with NTUA architectural students. Online Design studio with the help of software Webex and Autodesk SketchBook.

The immersion into the digital universe of education came out of the necessity (to protect the community from the virus) and therefore keeping the distance which was mandatory at that time. As a result, this urgent situation led to the expansion of digital potentials, which also happened with Design Studio.

At that point, tutors had to correct drawings from a distance, and there was no other way but through the interface of the screen and not that of the paper medium.

With the use of graphic pens, tutors suggest design corrections (Fig. 29, 30). Moreover, digital tools for design are employed, such as the Autodesk sketchbook application for Android and iOS devices (Fig. 31). The digitalization of the design learning process from the early stages of conception, even in the stage of first sketches and ideation, plus the necessity to continue the educational process from a distance, led to an alteration of the nature in the process of Design Studio's usual learning.

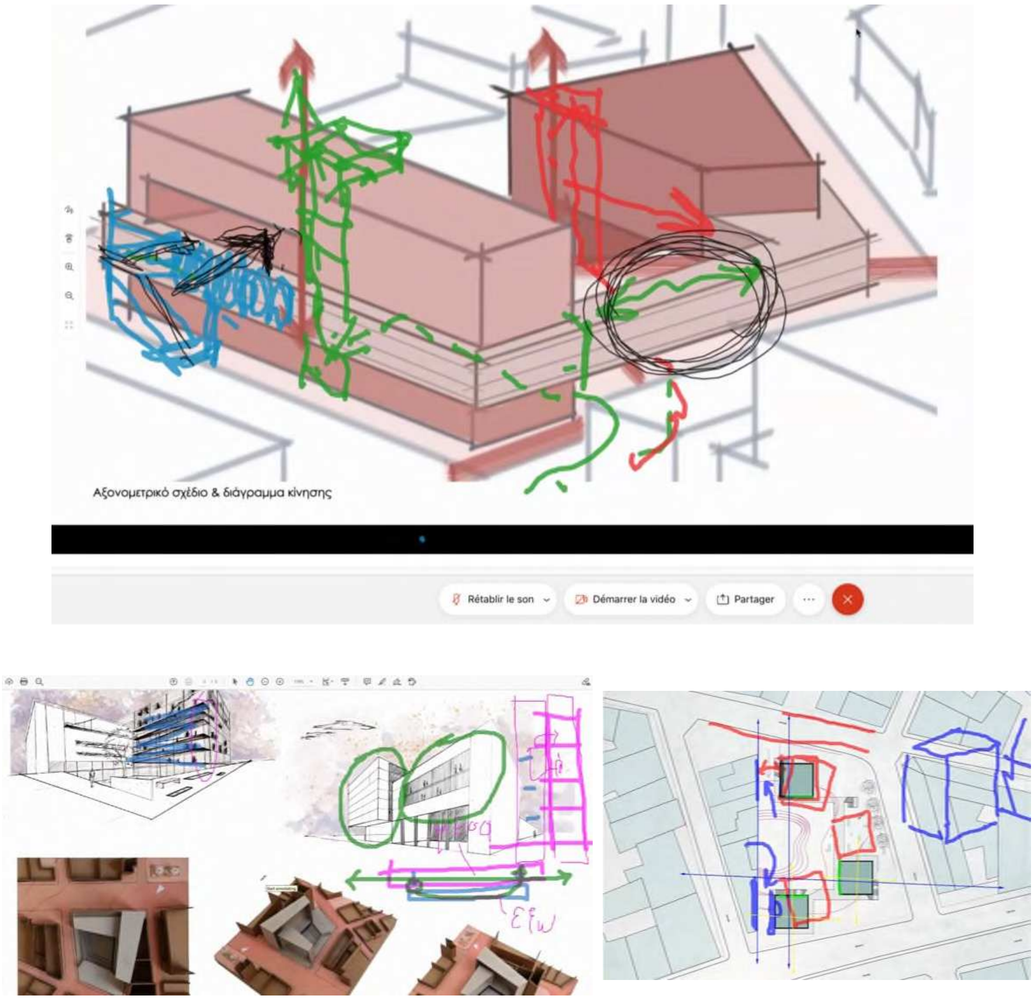


Figure 30. Corrections and critic sessions of the architectural project online, Design Studio 2021.

The students demonstrated incredible adaptability. By employing the previously mentioned digital tools, they collaborated and designed directly in the digital environment. For example, with the use of TeamViewer, a software that gives the possibility to manipulate a computer remotely, and Sketchbook app, they succeeded in working on the same drawings simultaneously, developing co-design in real-time by distance.

4.3.2. Observations

The academic year 2020-2021 was an extreme situation that is difficult to repeat in the near future. Our first observation is that although the students and the teachers appeared numb at the beginning concerning using the online platforms, they quickly adapted to the process.

Secondly, the digital DS and the use of the Miro platform permitted the groups to visit at any time of the day the works of their colleagues, exchange knowledge and influence one another. The digital media promoted peer-learning among architectural students, and the drawings and the presentations of students were collected in the digital dashboard. The knowledge of the spatial analysis and the teachers' corrections were simultaneously transmitted to all participants. This is a benefit that we do not meet in the traditional method, as it is difficult to have a close look at the corrections of others (Fig. 31).

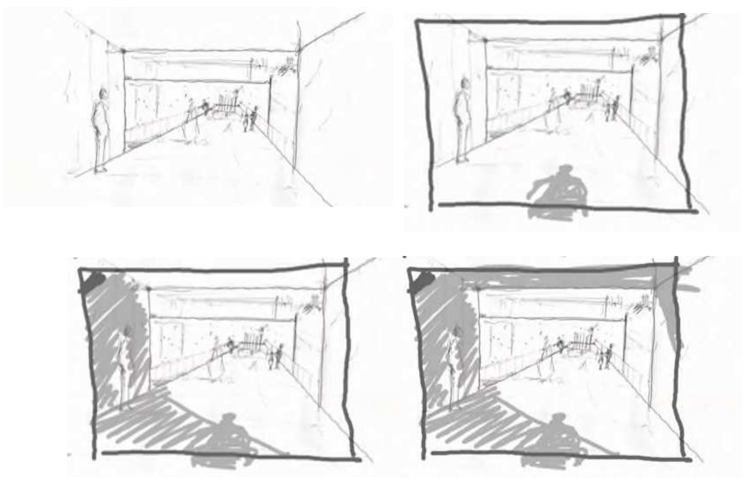


Figure 31. Online teaching shadows on perspective drawing, by prof. P. Vasilatos, Design Studio, 2020-2021.

Our third observation concerns the amount of new knowledge production for the students. The professors during the semester set an exercise of spatial analysis that was entirely held in the virtual environment of Miro (Fig. 32). They gave a list of known buildings to the students and asked each group to choose one to analyze. Their analysis should be based on the fundamentals of architecture, as we presented them at the beginning of the chapter. The advantage of this method was that students got knowledge in the duration of one week for many buildings. With this approach, they could take their time to observe the analysis of their fellow colleagues (Fig. 33).

Lastly, our fourth observation came in retrospect. We observed that the final design results of the students were advanced graphically, stylistically, more precise, and aspired to a particular architectural type of identity of each group of students.

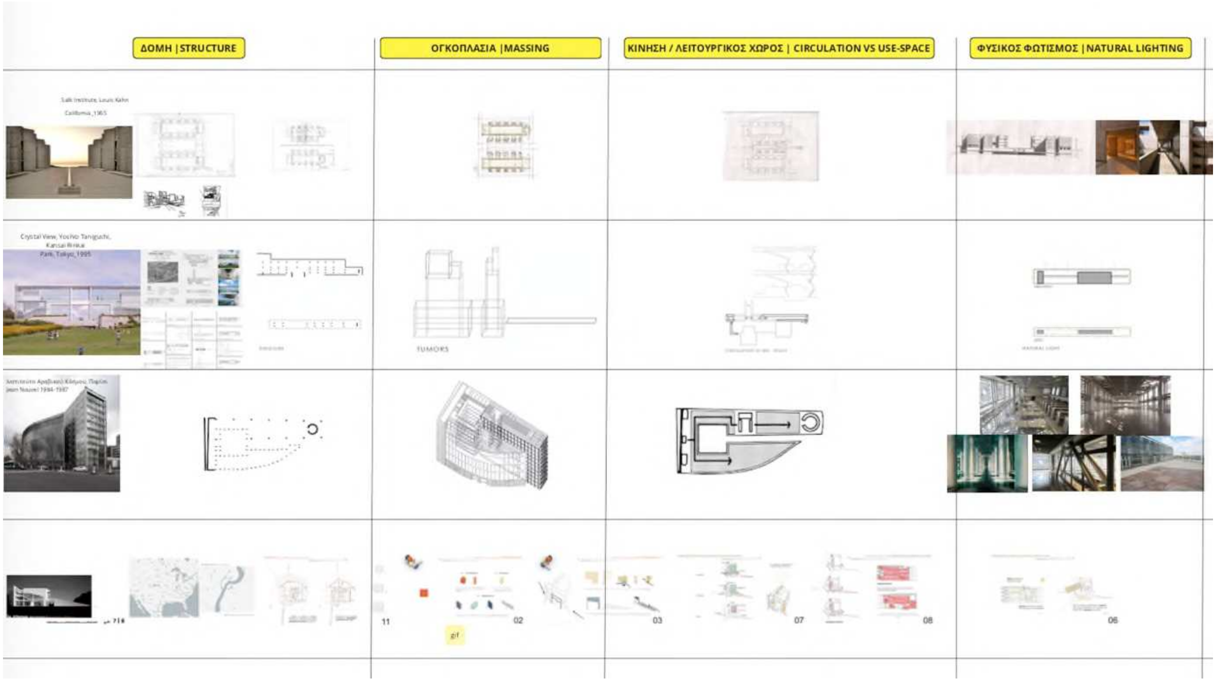


Figure 32. Online presentation of spatial analysis with Miro.
Source : prof. N. Anastasopoulos, Design Studio 7, 2020-2021.

To conclude, the experiences from the pedagogical process and teaching proposals with various digital tools integrated into the teaching of the course Architectural Design led to further experimentations with digital media that improved the architectural design result.

From these experiences, we rest assured that a hybrid method between traditional and digital methods during the DS learning process can only benefit the students and the project.

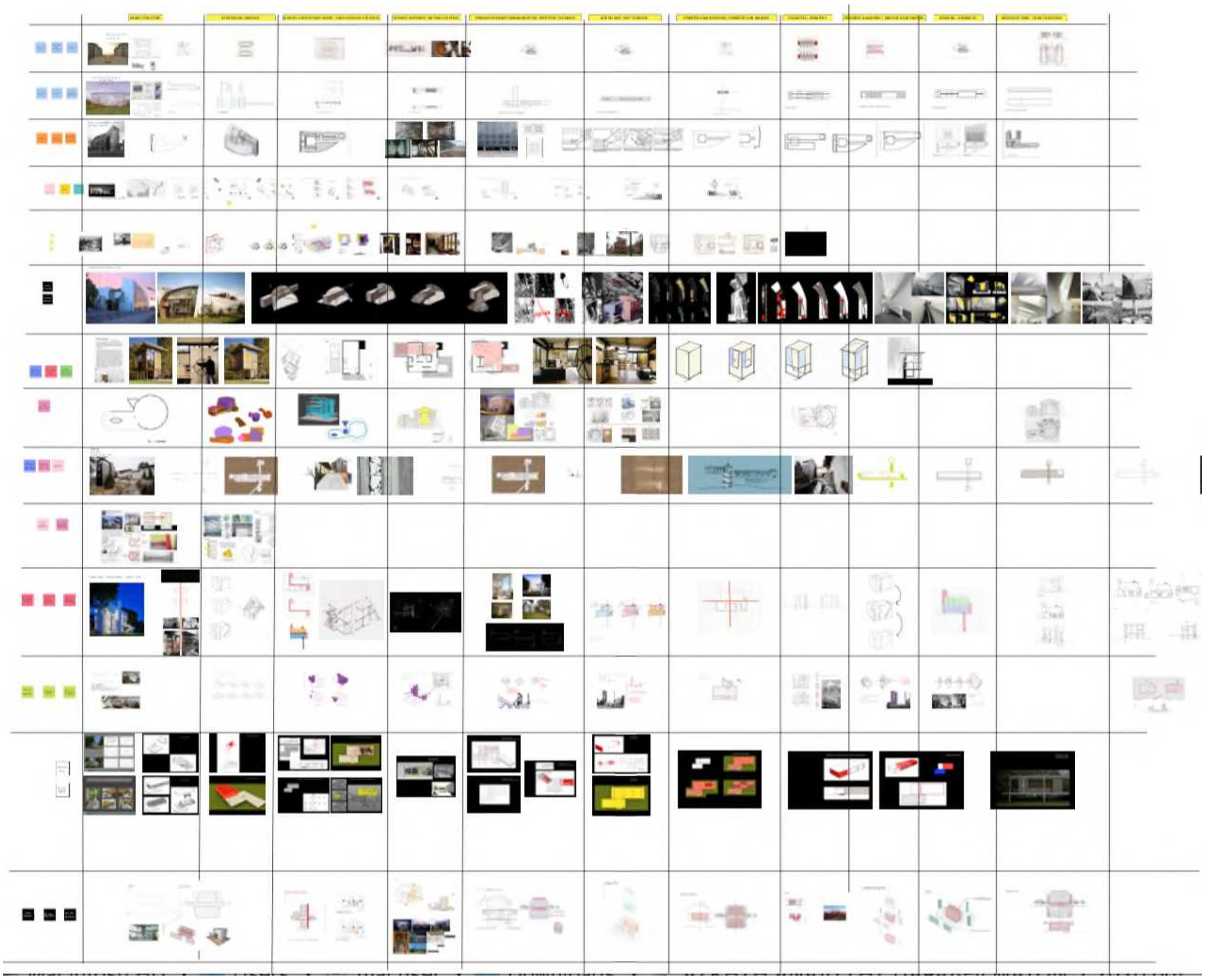


Figure 33. Overall dashboard in Miro. Source:
prof. N. Anastasopoulos, Design Studio 7, 2020-2021.

4.3.3. Questionnaire for Design Studio students

We present the results from the questionnaire (see: Annex 1a) we gave at the architectural students during the winter semester 2018-2019, (age group: 18-25 years old). Ninety-seven architectural students participated in answering our questionnaire regarding several aspects of this educational process. The questionnaires included questions about their experiences in Design Studio process. We employed the Likert-Scale method by Nemoto and Beglar, (2014) for the development of the questionnaire (Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree).

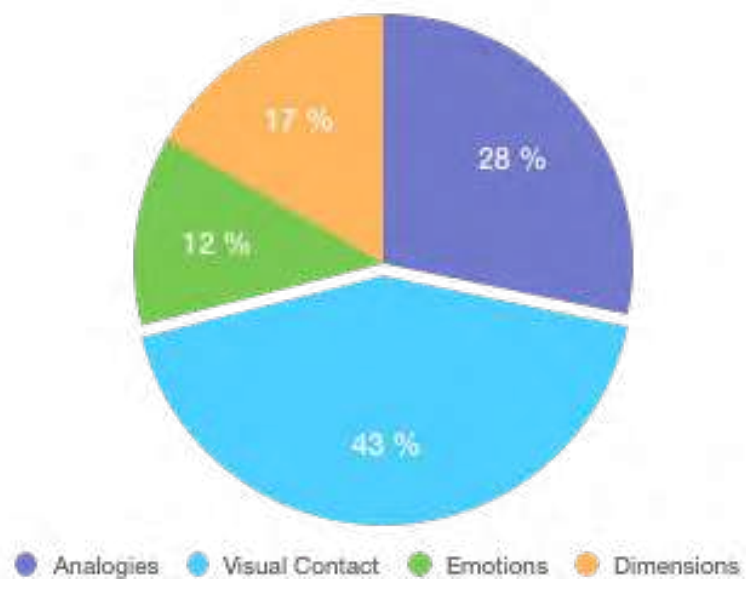
We differentiate the perception of reality through sensory criteria (five senses and emotions) and the perception of reality through quantification of sizes such as dimensions, symmetry, and materials. This choice was made in order to enable students to differentiate the elements of perception that come from the 'collective, external, objective surveillance area' (e.g. dimensions, symmetry, material) in relation to that resulting from the subject's hiring in its own' individual, subjective, internal surveillance area' (Kant, cognition and aesthetics).

The factors that we examined are:

- The perception of reality
- The working environment
- The initial stages of architectural conception
- The tools of architectural design
- Difficulty in architectural scales

Note: The sectors of the circular diagrams appear remoted from the circular diagram when rounding occurs in the percentages of the results. The charts are exported from Google Forms.

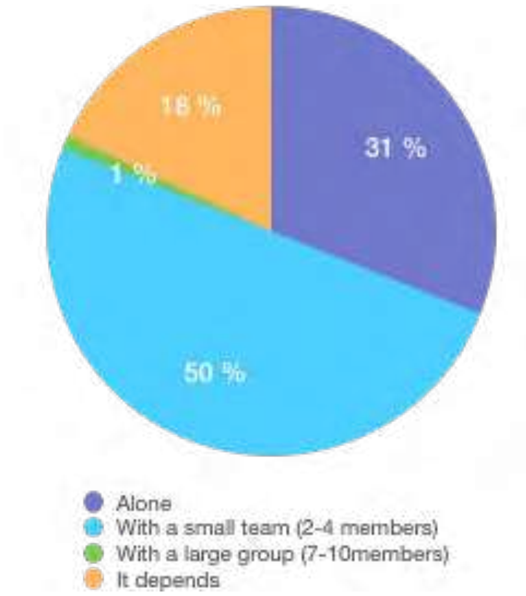
1) Perception of Reality and physical environment



43% of the students surveyed replied that they understand reality better through the senses and in particular through visual contact, while 17% perceive reality better through dimensions (Diagram 1).

Diagram 1. Perception of Reality, diagram.

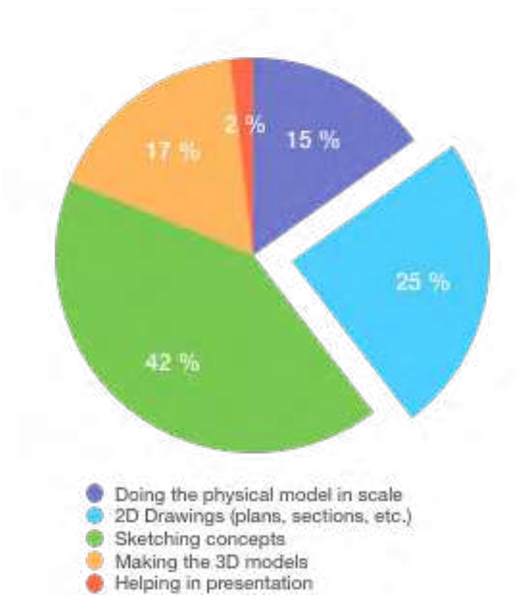
2) Working Environment



50% of the students surveyed replied that prefer to work and collaborate in smaller teams (Diagram 2).

Diagram 2. Working Environment, diagram.

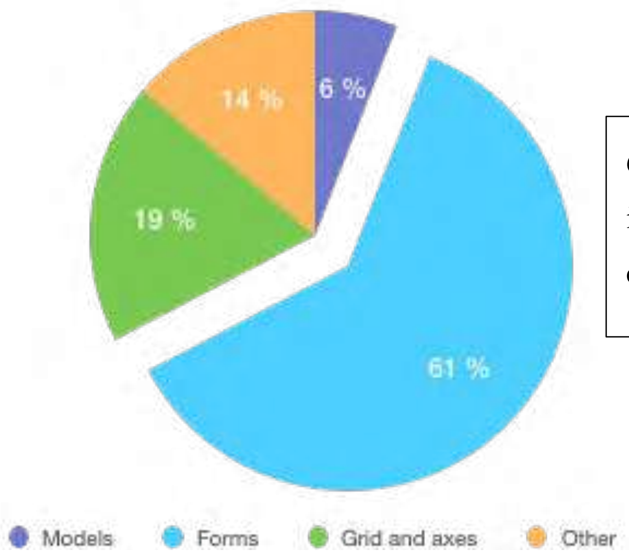
3) During the Design Studio



42% of the students surveyed prefer the creation of abstract sketches during the DS (Diagram 3).

Diagram 3. During the Design Studio, diagram.

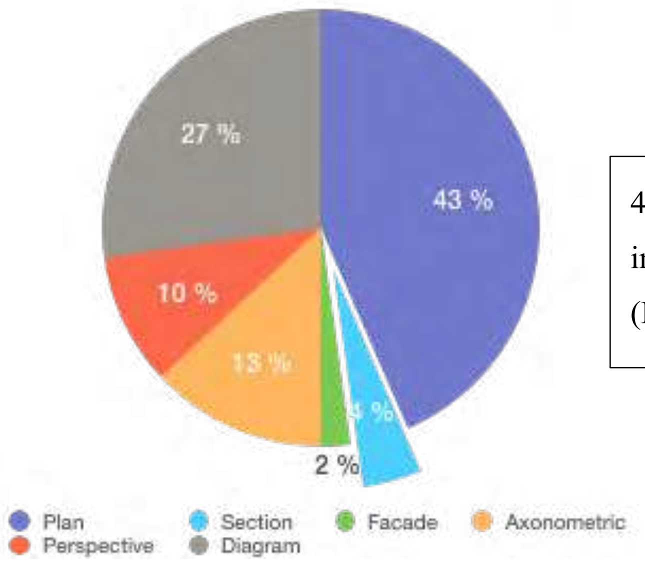
4) Initial stage of architectural design - Concept design



61% of the students surveyed prefer to initiate their conception with the creation of forms (Diagram 4).

Diagram 4. Students' Preferences about concept design, diagram.

5) Initial stage of architectural design – Project design

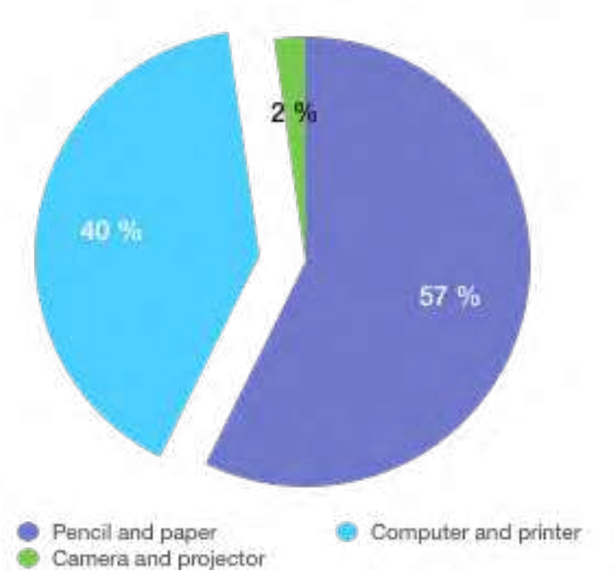


43% of the students surveyed prefer to initiate their project with 2D plans (Diagram 5).

Diagram 5. Students' Preferences about Project design initiation, diagram.

Overall, 76% of architectural students start conceiving from two-dimensional representations (plan, section, elevation, diagram), in counterpoint to the 23% that begins with creating a three-dimensional representation; 10% with perspective and 13% with an axonometric design. (Note: 1% is not included due to rounding for visual simplification of results).

6) Tools employed



57% of the students surveyed prefer to initiate their conception with hand drawings (Diagram 6).

Diagram 6. Students' Preferences about tools employed during Design Studio, diagram.

7) Scale transition

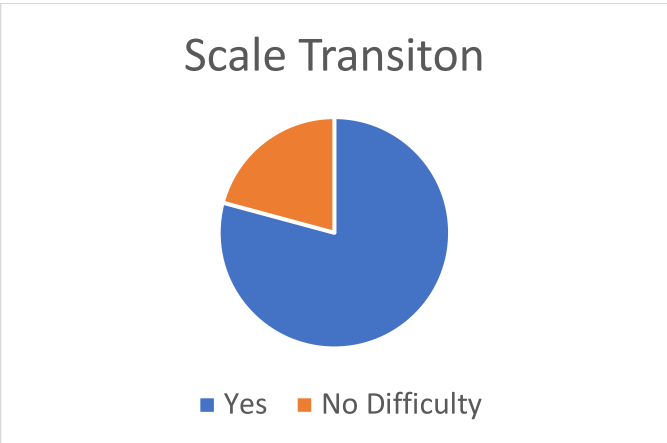


Diagram 7. Scale Transition diagram.

Table 2. Scale Transition Table

Architectural Students	Scale Transiton
Yes	79,2%
No Difficulty	20,8%

79.2% of participants replied affirmatively to the question: *Sometimes during the design, I encountered difficulties in conceiving the space on different architectural scales (1:2000, 1:500, etc.) and make the transition between them* (Diagram 7 & Table 2).

This is a fairly high percentage which means the architectural students are in need of new methods concerning learning design and representation.

Design include complex architectural issues as they deal with many different synthetic scales and levels of detailing. The scales on which a typical architectural exercise is analysed concerns urban planning (on 1:2000 and 1:1000 scales), the volumetric integration of the building into the urban fabric (on 1:500), local planning and landscape (on 1:200) and the scale of the project on 1:100 scale. Lastly, the students work on 1:50 scale for structural elements and materials. They also produce further technical drawings on 1:20 scale. In total an exercise may run through design reading and understanding on 4 to 5 scales, and the architectural conception is transformed from the abstract to technical through the architectural form.

Finally, in the questionnaire, we showed to the 97 participants the multistable image as presented in figure below (Fig. 34).

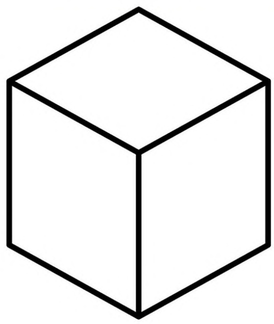
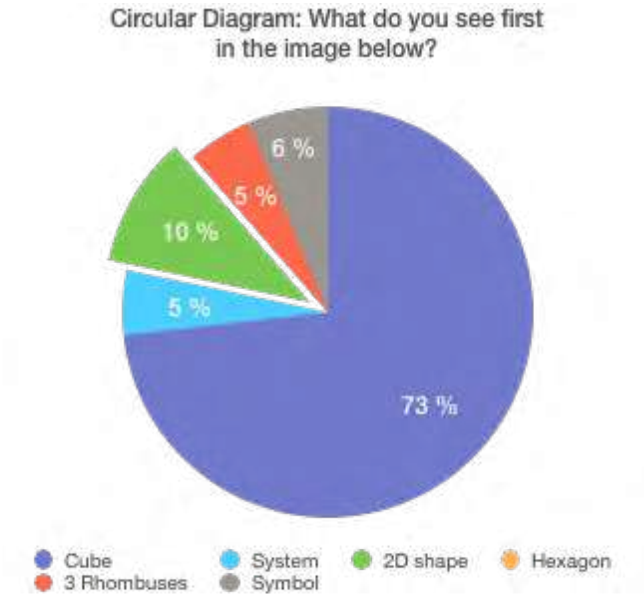


Figure 34. Multi-stable image.

We asked them to define what they see among several options. Although the objective interpretation of this image is that of a 2D sketch, 73,2% of the participants claimed they see a cube (Diagram 8). Multistable perception theory of neuroscience questions perception according to body-mind relation, cognitive biases, optical illusions as perceptual phenomena in which there are many unpredictable subjective changes, confirming the phrase that “true reality exists independently of perception” (Pillai et al., 2013).



What do you see first in the image below?

Cube	73,2%
System	5,1%
2D shape	10,3%
Hexagon	0
3 Rhombuses	5,1%
Symbol	6,3%

Diagram 8. Multi-stable image answers, diagram.

Moreover, in response to the questionnaire, 68,6% of students responded that architectural drawings imitate reality, while 77,9% stated that architectural design is a simulation or reality. The difference between simulation and imitation of reality is that the first represents a constructive thinking process, while the latter reflects mirroring existing components. The first process can be creative while imitation can be mechanical. Only a small percentage of 9,3% of students recognized intuitively the subtle difference between the two approaches.

Imitation and simulation of two concepts are interwoven with architecture and creativity.

Lastly, 79,1% of students would like to have Virtual and Augmented Reality courses at the core of their studies. 70,9% of respondents believe that Virtual Reality can improve the architect's perception of specific issues, and this can be done when the learner obtains a direct representation on a 1:1 scale. 69,7% who responded believe that Mixed reality media applications can help communication between architects with other sectors related to design, city planning, and building more effectively.

4.3.3.1. Summary of survey

Architectural students are familiar with digital environments, social media, and applications, and they seem to feel comfortable with technological devices. Students in architecture showed an augmented interest in learning more about virtual reality and its applications. At this phase of our research, we confirmed that professors in architecture were reluctant about how immersive digital tools can assist architectural exploration. Naturally, there are worries about the role of the future teacher, but we claim that teaching architecture does need some methodological modifications. During the time (2018) that this survey was conducted, the resistance to digital reality was high, and we possibly did not manage to have all the qualitative and quantitative data we needed.

Our observation is that after the covid-period, students and professors appeared more adaptive, flexible and willing to adopt hybrid digital methods of teaching the Design Studio.

Summary of Part 1

In this part, we visited several aspects of architectural education, Design Studio and Immersive Virtual Environments that assist the teaching process. We conducted questionnaires with architectural students and also participated in pedagogical experiences. We identified the lack of IVEs in architectural practice.

This research does not compare the manual drawing (by hand) and the digital as two opposing practices. We recognise the hand as the irreplaceable way to draw and to impose an architectural style. Also, we recognise its limits and potentials in terms of productivity. In parallel, we claim that these approaches complete the design process. By identifying the genuine prospects of the digital, by giving it more space in experimentation and practice, Design Studio can be considered an advanced architectural and technological practice in problem-solving engineering.

In Chapter 1, we examined learning theories that concern architectural education. Specifically, we focused on the architectural learning process of Design Studio. It is seen as a particular teaching method since it is a nonlinear learning process, including the use of digital and manual design tools. We observed a shift towards hybrid or mixed learning models in the Design Studio that combine technology, remote collaboration and design. The evolution of learning theories shows the pedagogical tendency in adopting learning models that combine the traditional tools with the digital tools of Mixed Media.

In chapter 2, we introduced the main characteristics of Mixed-Reality media. We also explored the origins of this medium. The main elements of Mixed Realities (MR) media, such as immersion, interaction and navigation in first-person mode view, can be beneficial for architectural education. The mixture of technologies can transform the architectural 3D digital models into interactive environments for exploration and discovery during the learning process of the Design Studio. Furthermore, we focused on the IVEs provided by MR technology. We investigated that the emergence of Augmented Reality can become a future digital tool for architects. We identified the Simulation Lab in NTUA as an effort that started in 2005 to integrate IVEs with AR in the architectural process, but the installation was abandoned.

In Chapter 3, we listed examples of MR applications and installations that can inspire future classrooms for architectural design in virtual immersion and reform the Design Studio process. The immersion on the 1:1 scale and navigation in real-time of a suggested designed environment, concerning human-size provided by suitable IVEs and MR technologies, challenge architectural education. We also spotted the limitations and the benefits of these approaches in relation to scale. Often the large screens represent spaces larger than they are designed. In contrast, the physical models (maquettes) made of cartons are smaller than the architectural object.

The challenge for the teacher in architecture is to produce immersive virtual systems that simulate the architectural conception accurately in terms of dimensions, proportions, analogies and materials. In addition, professors investigate digital tools other than CAD that can help increase learners' spatial perception and creativity. IVEs can be environments that promote accuracy and creativity. For this purpose, it is necessary for architects, developers, artists and experts from other disciplines to collaborate.

In Chapter 4, we analyzed our two-semesters teaching experiences during the Design Studio course in NTUA. Architectural students are familiar with digital environments, and design. We conducted a survey among architectural students, and they showed an augmented interest in learning more about MR applications; they also indicated the difficulties they met during DS.

In the next part, we develop experimentations regarding our findings that aim to replace the use of MR media in the process of DS.

Part 2: EXPERIMENTATIONS

In this part, we present the development of our digital experimentations. During this thesis, we developed five digital applications to reconstruct the course of Design Studio and complement the learning process with hybrid learning models.

The field of Mixed Realities and architecture is vast, so we specify our scope towards developing educational proposals. For reconstructing the course of DS, we suggest the following teaching proposals about the integration of Mixed Reality media in architectural studies:

- Teaching proposal 1: Mixed Reality applications can enhance the architect's perception of the 1:1 scale and thus the understanding of other architectural elements (memory – learning).
- Teaching proposal 2: Mixed Reality poses parameters of perception and understanding of reality and the integration of the architectural object.
- Teaching proposal 3: Mixed Reality can integrate motion (movement in First-Person view) as a perceptual sensor of real space in the pool of digital creation and architectural representation.
- Teaching proposal 4: Mixed Reality can reeducate the designer's body as it facilitates the understanding and the design of space.
- Teaching proposal 5: Mixed Reality helps deepen the three-dimensional representations of the city and the building.

New tools emerge from existing technologies to develop architectural education.

We work on adapting the immersive virtual environments during conception and the connection between conception and immersion grade.

Chapter 5: Framework of experimentations

The thesis subject is within the broader framework of a constant dialogue between design tool, and culture connection. More specifically, it reflects the digital transition and how it affects daily life, education, and architectural design. This research aims to develop the concepts, methods, and tools that can foster creativity and implement solutions adapted to the complexity of the problems of design, aesthetics, and philosophy that architectural students face today and in the future.

5.1. @postasis Platform

@postasis: Virtual Artistic Laboratory is conceived as a proposal for a modern artistic workspace that allows remote collaboration in the context of educational activities such as courses, seminars and art projects. It combines participatory real-time artistic and design activities in the interconnected physical and virtual 3D space.

This framework develops the technological platform @postasis and appropriate educational methodologies, which allow its use at various levels and from different places (teachers, artists, students and programmers can contribute to upgrading its functions).

The project @postasis: Virtual Artistic Laboratory is based on the multilevel research[19] which started from the Athens School of Fine Arts. This project was developed through international collaborations at an EU level, with the participation of two Universities and two artistic centers, between four EU countries: Athens School of Fine Arts (Greece), University of Paris 8 (France), Argenia (Italy) and MAD Emergent Art Center (Netherlands).

@postasis is pronounced "apostasis" and in Greek means distance, a signifier for the remote collaboration of the participants. This protocol permits students and teachers to visit the

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[19] Santorineos M., Zoi S. (2011). A proposal for a digital art laboratory that meets contemporary educational and experimentation needs. 5th Annual Edition of INTED2011, Valencia, Spain.

same virtual environment simultaneously by distance and to develop interacion between them and the environment.

The architecture of the platform's system consists of three autonomous but interconnected spaces: the communication and exhibition space, the virtual creative space level and the information space, as it appears in the figure (Fig. 35).

The actions of the @postasis project developed in these three stages, and multiplier events took place in all the four countries that participated, where tutors and students exhibited their projects.

The platform's virtual creative space is based on the Unity 3D game engine. The platform includes a series of reusable (front-end) tools that enrich the creative virtual space and allow learners the implementation of complex design ideas without prior technological knowledge (e.g. interfaces with elements of space and Internet-of-Things).

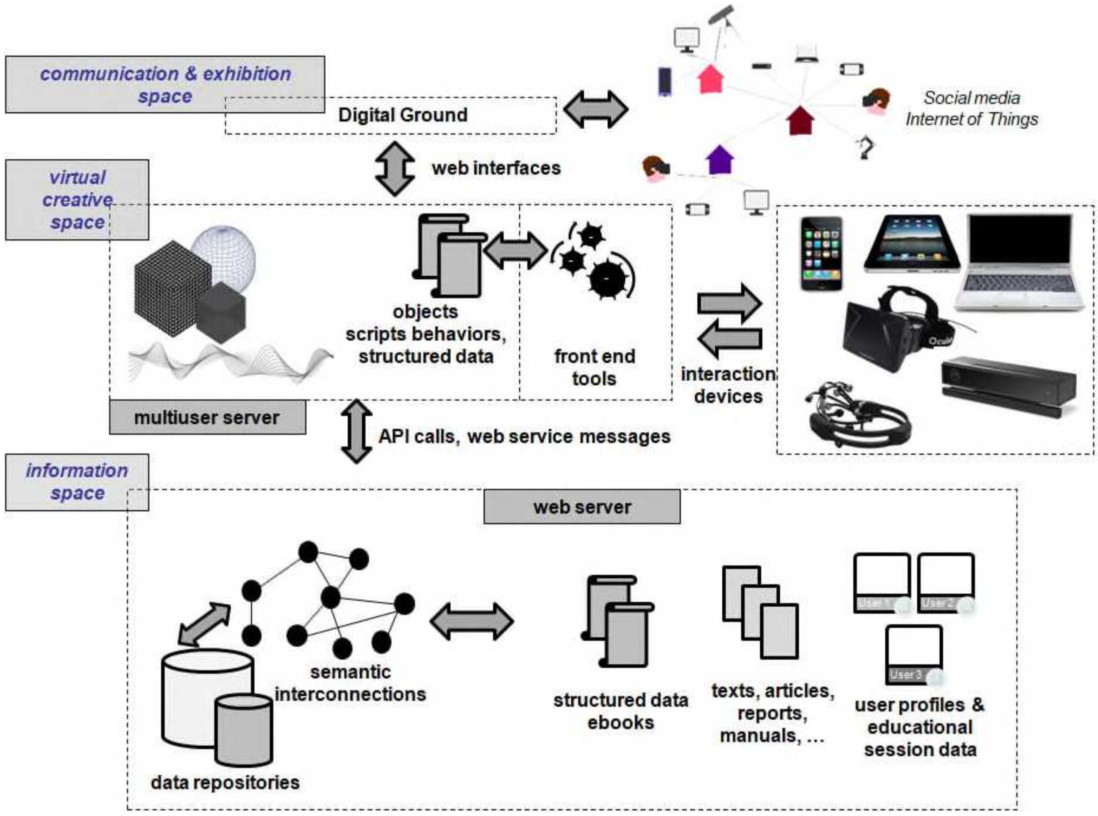

Figure 35. The Architecture System of the @postasis platform for multi-user and real time experience, Santorineos & Zoi (2018).

Access to the @postasis platform is assured upon communication and request to the project's scientific team through the online site[20]. The purpose of this project is to give the possibility to learners and teachers to create 3D visual projects online and participate in collaborative projects that are in progress, based on the availability of the infrastructure of the platform. Teachers, mainly in digital arts and architecture, who wish to create or expand a course at an international level can use this platform to collaborate with other laboratories.

Furthermore, the platform can be used by PhD candidates interested in working in a virtual space to study the platform at a conceptual, educational and technological level. The students can collaborate through their courses and continue the research on the evolution of the platform.

The @postasis platform allows participants to take a remote course in real-time through a 3D virtual environment, utilizing and incorporating elements of physical space (such as devices, sensors, etc.). It enables the use of modern technological structures such as the digital design in the virtual environment, the participation and interaction through the body, and the use of interconnected objects (Internet of Things), combined with new educational methodologies to produce original courses in a global scale.

In addition, the @postasis platform, as a virtual environment for experimentation, triggers researchers to raise awareness about artistic, technological, and social issues related to digital culture and mixed reality. The @postasis platform (basic web structure and tools) and the accompanying material refer to:

- A programming environment (@postasis framework), based on the Unity 3D game engine and the Photon server
- Installation and user manuals
- Manuals for developers who want to extend the functions of the platform
- Educational material with practical examples for teachers and educators
- Theoretical material: preparatory courses, also practices that have emerged from research on the platform itself
- Innovative joint methods and real-time experimentations developed among the partners

[20] http://apostasis.eu/

- Large-scale participatory events in physical and virtual space
- Innovative educational material in different formats (e.g. ebooks, smart objects, applications, videos)

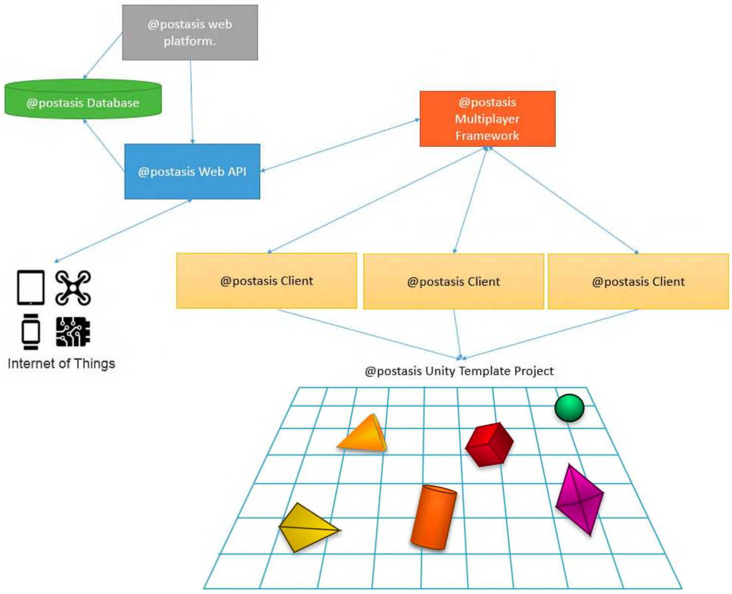

Figure 36. @postasis platform concept for Unity 3D software,

(Zoi, 2019).

The structure of @postasis platform is based on building digital applications for a server (@postasis Database) and a client (@postasis client) (Fig. 36). The server hosts the clients and allows interaction in the virtual environment.

The results of @postasis actions and the platform itself are available to the academic community through an open license of OER / Creative Commons. @postasis is an Open Resource Learning (OER) platform labelled as the best educational practice in 2020 (see: Annex 2). The purpose of the @postasis platform is to provide the 3D digital space as the environment of creation and interaction. Multiple events were held in each country, where each team presented their work.

5.2. Introduction to the experimentations

During this thesis, we participated in the EU project of @postasis platform. The author was a member of the scientific team of the University Paris 8. Our role as Engineer of Studies (Ingénieure d' Études, 2018-19) included the mission to develop a plug-in for the platform, organize and host the Multiplier event in Paris (2019). In parallel, the author was a PhD candidate and a teaching assistant in NTUA. Therefore, we had the opportunity to develop mixed experimentations regarding architectural education using the @postasis platform to provide educational models of Mixed Reality methods.

We developed digital applications about learning design architecture using technology:

- Such as Tablets, Desktops and Mobile devices
- Software use, such as Unity 3D, Sketch-Up, Rhinoceros, Grasshopper, Clojure, C #

The focus was on designing interactions in the virtual environment based on design analysis, behaviour, and constructive spatial synthesis.

Using this digital platform for artistic creation and collaboration, we created our first experimentation of educational model for architects concerning the Parc de la Villette in Paris (Educational Model 1, see: Chapter 6).

In addition, as mentioned, the scientific team of Paris 8 University mission was to develop a plug-in for this platform as a digital tool for creating dynamic objects and systems which allow a precise determination of scenarios of interaction (between virtual objects). We developed the Behaviour Interactive Interface (BII) plug-in, which consists of our second experimentation of the educational models suggested in this document (Educational Model 2, see: Chapter 7).

Later, since the author was a teacher assistant in the NTUA in the Design Studio (2018-2019), we developed experimentation where we applied the BII to the architectural project of a group of architectural students. This convergence between digital and traditional teaching methods consists of our third experimentation (Educational Model 3, see: Chapter 8), from where a publication emerged in the eCAADe conference (2019) in Denmark.

Later, we continued independently the collaboration with MAD Emergent Art Center in Eindhoven, Netherlands, where we developed an AR application for a city tour in the city of Eindhoven, and consists of the fourth educational experimentation, which relates the physical environment of the city with evoked digital content in relation to GPS coordinates (Educational Model 4, see: Chapter 9).

Lastly, with developers from Eindhoven, we managed to suggest an AR CAD application, named ARtect, which goal is to assist the Design Studio learning process on-site (Educational Model 5, see: Chapter 10). We presented the ARtect prototype at the IEEE conference (2020) in London via Zoom.

Before the reader is immersed in the details of our experiments, we created this schematic code (Fig. 37) that will assist us later in the analysis of the educational models. The white circle signifies the virtual or digital environment, while the black circle signifies the real or physical environment. The intersection of these two circles represents the Mixed Reality experience of the user with the technological media.

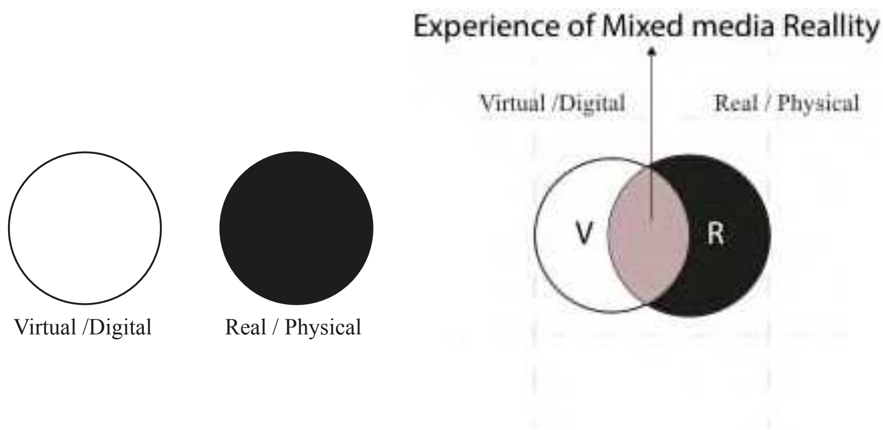

Figure 37. Schematic representation of Mixed Reality.

Chapter 6: Educational Model 1-Folie No5 @postasis

We are experiencing with @postasis framework which is a webinar tool to facilitate research and exchange of educational material among designers, artists, software engineers, and architects. This semi- immersive virtual environment in 3D serves as a vessel, and common ground for learning and participating by distance.

Explanation of graphic symbol:

In this experimentation, the physical environment of the Parc de la Villette includes the virtual environment of the Parc de la Villette as a representational system. The two environments are converged in the projection screen, and the user has immersed into the physical and virtual environment simultaneously (Fig. 38).

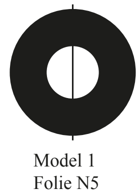

Figure 38. The graphic symbol of Educational Model 1.

Type: Simulated Reality, Mixed Reality, Semi-VR

Period: 2018-2019

Place : Parc de la Villette, Paris, France

The suggested course title is *Co-learning in Architecture with the use of interactive hyperlinks in @postasis platform 3D multiuser virtual environment. The example of the pavilion "Folie Numérique" in Paris as a virtual interactive educational environment.*

Keywords: *Architecture, Digital creation, Design, Virtual Reality, 3D modelling, hyperlinks*

Framework

This educational model presents a virtual class about learning architecture based on physical space and webinar interactive digital means. It belongs to a series of courses that exist online concerning the @postasis platform. Our contribution to the open online educational material of this platform develops an interactive virtual online classroom (Fig. 39) for architects at the space "Folie Numérique N°5", Parc de la Villette, in Paris. The virtual classroom is simulating the real space of the building and hosts a virtual exhibition space. The educational model is presented in the article "*Co-learning in Architecture with the use of interactive hyperlinks* [21]".

For short, we call this educational model "Folie N5". Folie N5 suggests an educational model sample of a larger methodology that aims to identify the relations between virtual and real space as part of our conducted researches in the Laboratory of Architecture MAP-MAACC, in ENSAPLV. The educational model is combining a transdisciplinary approach and digital creation. Studies and several educational materials focus on architecture and public space, design of cities and virtual environments. Architecture history, game design disciplines, interactivity, and virtual reality, consist of the scientific and technological anchoring for further

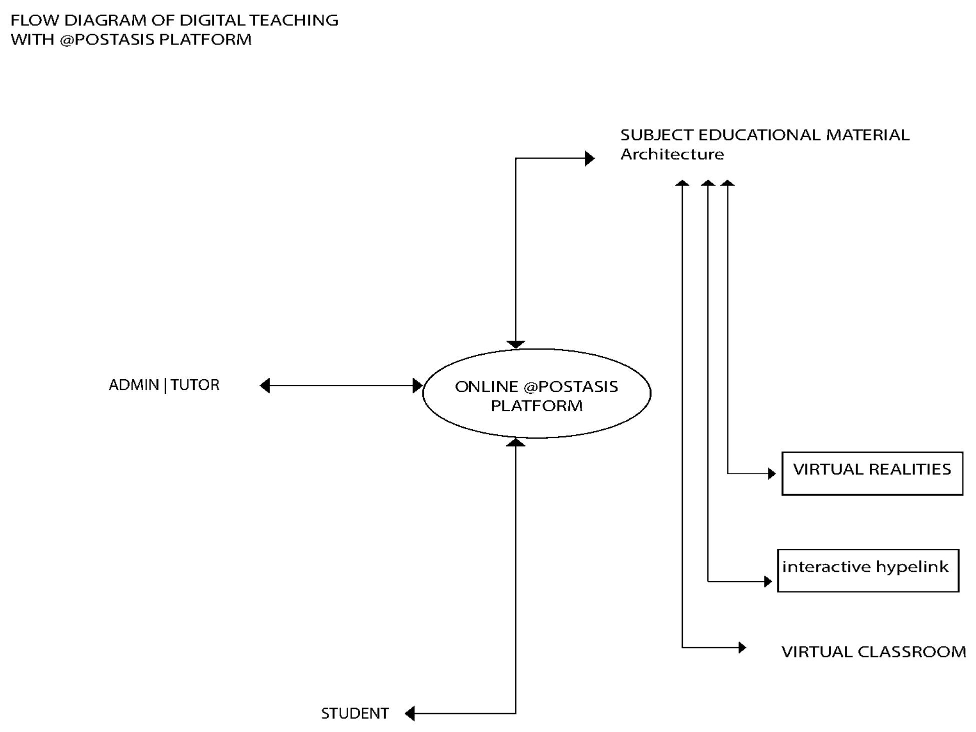

Figure 39. Flowchart of @postasis virtual classroom and the role of the teacher, 2019.

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[21] *Co-learning in Architecture with the use of interactive hyperlinks*. (2019). @postasis - Virtual Artistic Laboratory. Retrieved 6 January 2021, from here.

research in architecture. The teaching approach proposed is structured in technical terms, flexible in visualisation and conception of space.

Furthermore, the objective of this course focuses on the educational process and methodology for co-learning and exchange. Students and tutors participate equally to create the interactive multiuser virtual classroom (indicated in the flowchart, Fig. 39) as a space of artistic expression and knowledge about architectural design. A technical description is presented to create an online virtual interactive classroom and communicate through the @postasis chat platform with other virtual attendees (Fig. 40).

Figure 40. @postasis Enter the virtual online room, Virtual Attendee, 2018.

Made with Unity 3D and @postasis Framework, during the study engineering of the European project @postasis: Virtual Artistic Laboratory, this course is proposed by the author as a member of the International Relationships Service of Paris 8 University, and Engineer of Studies at that time and PhD candidate in architecture. It portrays a custom educational tool for students in architecture design, fine arts and history studies.

6.1. Educational Objectives

The objective of this educational plan focuses on the synthesis of the navigation in the 3D digital environment. It aims to expand the limits between research and architecture through new technological approaches in education within a 48 hours-seminar. The virtual online classroom introduces a real-time multiuser environment, a room of exchange and shared experiences for learning through interaction, play, exploration and discovery architecture in virtual environment.

During the Third multiplier event of the @postasis platform, at Villette's park, more than 60 participants visited and tested the application (requirement of the event). @postasis is an Open Educational Resource, and it was a prerequisite to test it with the grand public (as the event was free and open to everyone).

This exercise was held as a seminar of 48 hours for the participants of the event. It can take place as elictive course of architectural design with digital tools, during four months of 3 hours course/week for 16 weeks. It is an educational process for theoretical and technological background where designers, artists, engineers, and other hybrid technicians can participate.

For students to understand several design concepts regarding architecture, they are asked to design a virtual space, as an interactive virtual scene.

The main focus of the course is on the educational process and specifically on methods of learning, perceiving and evaluating architectural design proposals in a collective way while the students of architecture are using digital by distance platforms.

- Physical space

Folie Numérique building is part of the design of Parc de la Villette by the architect Bernard Tschumi (1987) (Fig. 41). The Folie Numérique is a small construction of three levels and a layer of the general master plan of the Parc de la Villette (belonging to a larger cluster of Folies, like confetti).

Figure 41. View towards la Géode from
the first floor of the Folie Numérique N5,
Parc de la Villette, Paris.

Furthermore, the students with the tutors think of how this place would be more informative by synthesising deconstructive spatial elements and adding several narrative aspects to the virtual environment of the Folie N5. Lastly, this is a shared mixed reality experience with the multi-user possibility provided by platforming the real space.

The goal was to merge in one experience, the virtual and the natural environment. While in the architectural study, we initiate design from the virtual towards the real environment; in this case, we inversed the method (Fig. 42). We tried to simulate virtually an existing environment. We attempted to host a virtual exhibition about the park's architecture in the virtual environment of the park while we were at the physical space (Parc de la Villette). In our case, at the Folie Numérique N5 physically and virtually, we informed the participants about the capabilities of the digital platform functions for remote collaboration. Presence in the virtual environment of an e-classroom was one of the subjects of the proposal.

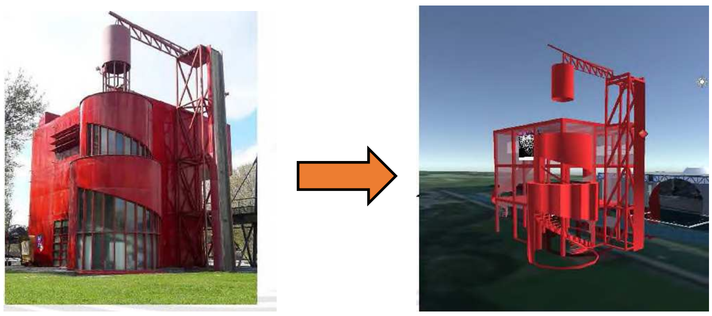

Figure 42. Folie N5, From real to virtual environment as learning process for architectural studies, April 2019, Paris, France.

The educational objectives also focus on learning to observe the geometrical space of the surroundings from an architect's point of view, which is also culture. For this course, exchanging knowledge about the architecture of Park's de la Villette and the «Folies» led to developing the first educational model following the principle from real space to virtual. We created a 3D interactive virtual environment as a representation of the Park. The virtual environment is not 'constructed' or made in the same way as the real one, and therefore it is different when it comes to design.

Virtual space exploration as a simulation of the real environment occurs in real-time while experimenting with digital content like maps, videos, animations, images, sound, and web pages (URLs). The 'real' or 'natural' environment and the object of architecture are 'increased' with different forms of materials (Fig. 43). We used the method of URLs hyperlinks to connect content through web pages; therefore, it is necessary to follow certain technical constraints. The aim is to inspire students of architecture to experience digital tools for different conceptions.

During the experimentation, the method we developed in the virtual classroom is based on hyperlinking design.

Learning capacity and comprehension regarding architectural notions (such as scales, measurements, dimensions, transformation, transmission) are presented during the course. The knowledge about connecting real and virtual environments permits students to attain new skills, perform and visualise architectural design proposals.

Hypermedia is attached to the notion of "hyperlink" and "hypertext," which relates and connects two digital elements (URLs) like "portals" to web pages.

Figure 43. Data that accompany a virtual environment. Extended content like text, sound, location, videos, educational material.

Several existing theories and researches relate hypermedia with the learning capacity. The first argument in mixed media literature is that this kind of media offers more control over the virtual environment for the student or the hypertext's reader. In addition to that, researchers claim that hyperlinks augment the playing field among students of various abilities and interests and develop collaborative learning and commitment during the educational process. Lastly, psychologists include the idea that the hypermedia model is closer to the brain's structure, at least visually, compared to the printed text.

Through the @postasis interface of interactive objects, connections are created between physical space and cyberspace of the web (Internet). During this course, the architectural student is initiated to basic theoretical frameworks about notions of "topos" (local landscape) in architecture. Secondly, the learner explores new aspects of design with virtual scenes that combine geometrical perception, visual interactivity, and navigation. Finally, we design also courses that are based on research about digital spatial representations destined for architects.

The research-based methodology provides architectural students with a practical and theoretical educational package about real and virtual spaces. Hyperlinking is one of the many methods proposed for learning and understanding the interconnection between 3D models and other educational materials. This educational model follows the guideline, which is to transfer real space into virtual spaces.

The proposed method combines mixed realities-platforming with real space-prototyping with the use of the @postasis platform for connecting users in the 3D multiuser educational environment.

6.2. Implementation

Prototyping using ready-made 3D objects

The proposed method for learning architecture is based on using the digital platform @postasis to support distance collaboration for learners. For the proposed method, we need a laptop computer. Moreover, prior technical knowledge in terms of designing a 3D environment is not essential. The course presents a "know-how" with hyperlinks and "ready-made" 3D models.

This method can reinforce the cognitive impact of the student's sense of presence from the virtual space into the real space. The technique refers to creating an educational mechanism with digital tools, where different virtual spaces are identified and related to the physical space. As a case study, the course is a unity package (Unity.Package) that includes a Parc de la Villette simulation with ready-made 3D models. The demonstrated example, was built for server and client, a demo digital application, “Folie Numérique N5”.

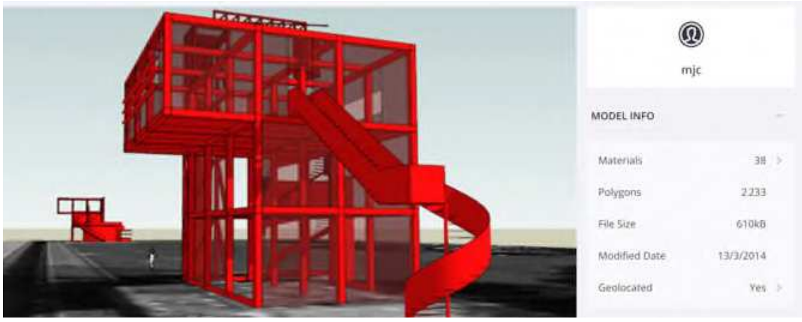

Figure 44. Using 3D ready-made model, is already a collaborative work for designers.

The application Folie Numérique functions as a 'narrative' and 'reflective' virtual environment where the interactive installation is interconnected with the physical, virtual spaces and webinar space. Narrative because the user of the application can receive information about the physical environment. Reflective because the user can reorientate, comparing physical and virtual features.

Several 3D models are used for experimentation and set the virtual scene of Folie N5 at Parc de la Villette. Specifically, we chose the ready-made 3D models of the Folie N5 downloaded for free from the SketchUp warehouse (Fig. 44). The design learner may use any 3D model to create custom virtual scenes, which is part of the creativity of the process. The convenient model for our experiment is a low-polygon model exported as a *.obj* file (object).

For this application, we also used the following models from the 3D Warehouse Sketch-up to form the virtual scene: 1) Cité des Sciences et de l'Industrie, 2) Cité de la Musique, 3) La Géode (Fig. 45).

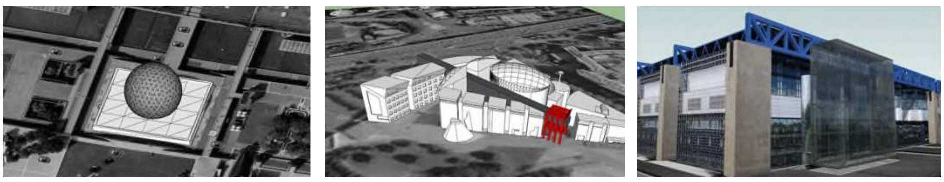

Figure 45. La Géode, Cité de la Musique, Cité des Sciences et de l'industrie, Paris (viewed from left to the right). Retrieved ready-made 3D models.

Moreover, in the virtual environment setting, we also simulated the canal that passes in front of the real building of Folie N5 to synthesize natural and artificial elements of the park in the virtual experience.

The students learn how to implement 3D models in the @postasis platform and Unity 3D during the course (Fig. 46). This process gives the asset of navigating the digital landscape in first-person controller (FPC) view mode. Further, we connect several 3D objects in the virtual environment with links URL online, using informatics language (C#). The notions of interactivity and transformation are ideas for further research in architecture. This educational engineering aims to develop the imagination of the students.

The course and the executable files (.exe file[22]) from Unity 3D as a package exist online on the link[23] of the @postasis platform, and it contains the following documents to download:

a) Folie demo executable archive for @postasis built for server and client, compatible with Windows and iOs
b) Co-learning Architecture with hyperlinks presentation
c) Co-learning Architecture Seminar Outline

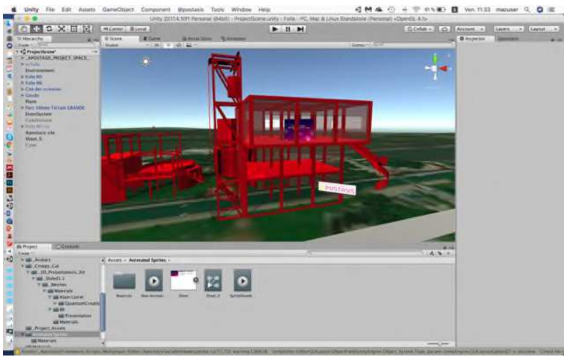

Figure 46. Implementation of 3D models with Unity 3D.

The main characteristics of the application are:

1. Distance participation capability
2. The virtual online classroom allows institutions from different cities (e.g., Paris—Athens) and students to attend virtual courses and exhibitions on a global scale.

[22] An executable file (exe file) is a computer file that contains an encoded sequence of instructions that the system can execute directly when the user clicks the file icon.

[23] http://apostasis.eu/EDUCATIONAL-MATERIALS/ArtMID/1647/ArticleID/1218/Co-learning-in-Architecture-with-the-use-of-interactive-hyperlinks

Similar to the hierarchy of the architectural project (see: Part I, Chapter 4), likewise, the virtual environment presents several similarities in prioritising the order to "build" the application and "run" it. Hierarchy of the Unity project is necessary to set up and use the interface of this platform, to avoid technical interference. It will take several minutes to install the @postasis software to a new Unity Project. The students work exclusively on the *project scene* partition of the platform workspaces and run the tests in play *offline mode*. No previous specific technical knowledge, as mentioned, is needed to use the platform, and basic Unity 3D knowledge is sufficient while it is accessible through numerous tutorials online.

The learner can navigate in the virtual park and interact with the environment by clicking on several virtual objects (triggers). Moreover, the user of the application can move from the stairs in the three levels of the virtual building (Fig. 47, 48, 49).

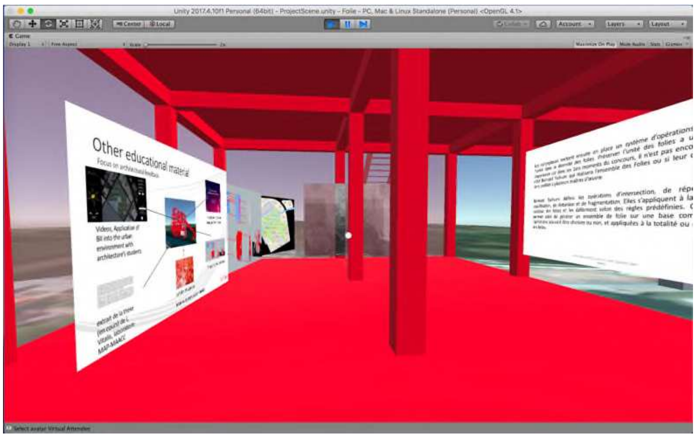

Figure 47. Virtual Exhibition in virtual space of Folie Numérique N5 (Second Floor), Presented at the 3rd multiplier event, Paris, France, April 2019.

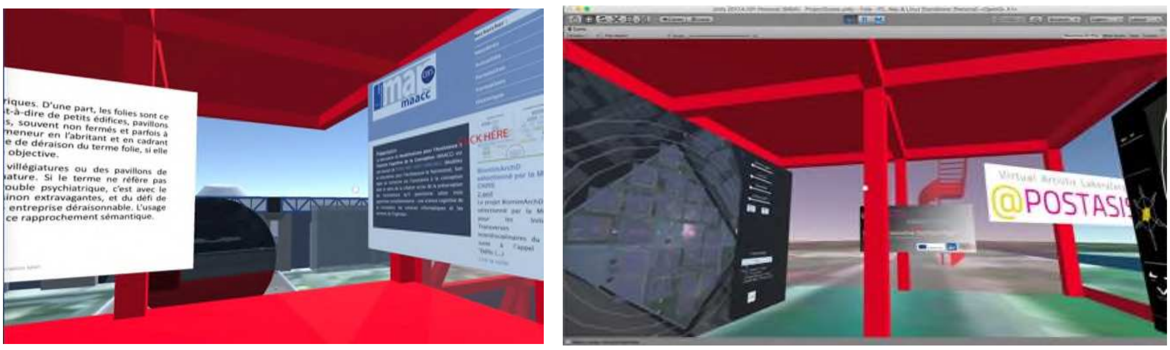

Figure 48. (right) Entrance in the virtual Follie Numérique (Ground Floor), (left) Space for video projections and view toward the virtual Géode (First Floor).

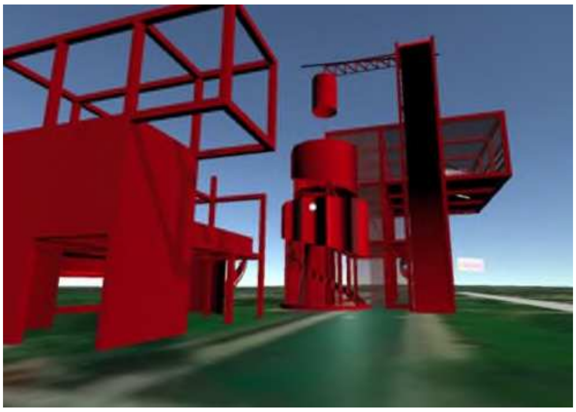 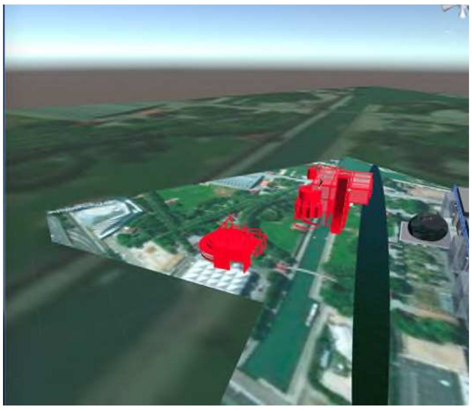

Figure 49. Navigating the virtual Parc de la Villette.

6.3. Technical Requirements and Preparatory

The preparatory stage includes using a personal computer (pc) or a mac, where Unity 3D is installed. In addition, the course includes software use.

The software we used can be downloaded free from online three links like below:

- Unity 3D 2017.4.10f1 free version hub (https://unity3D.com/fr/get-unity/download/archive)
- a free version of Unity Hub V.2017 or Unity 2017.4f
- @postasis Framework v.2.3 or current (downloadable at www.apostasis.EU)
- 3D Software: Sketch Up 3D 2017, Mesh Lab, Open Source, http://www.meshlab.net/

6.3.1. Hyperlinking

We attach the following C# script to 3D virtual objects to transform them into virtual buttons. When the user clicks on these buttons (mouse click), the users are directed towards the web page linked to the virtual object. The script we use follows, and we attach it to several emplacements into the virtual space.

Script for creating interactive Hyperlinks:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
public class LinkClick: MonoBehaviour
{ void OnMouseDown ()
{application.OpenURL ("http://apostasis.eu/"); }}
```

This exercise helps the students develop their digital 3D modelling and scenography skills by placing the interactive objects according to the circulation and movement in the virtual environment (Fig. 50). PhD students from MAP-MAACC Laboratory added texts, images, and drawings, from their works that refer to the Park and the real space of the Folie Numerique (in the three levels - Ground Floor, First and Second Floor), such as texts and sketches of the Park concerning the architecture of space (Fig. 51).

The demo was displayed during the Third Multiplier event in Paris, held in the Folie N5. The guests and the participants of the conference also put their presentations in the virtual Folie N5. The public that did not assist the conference could revisit in parallel the presentations of the speakers. The virtual Folie N5 worked as a virtual online classroom and virtual conference. It is a concept for further development in contemporary education to converge physical and digitally geometrical space into mixed reality applications.

6.4. Evaluation of Educational Model 1

The educational advantage of the webinar space is that we can test and evaluate 3D models by distance, creating a co-working digital environment.

The experience of the virtual online classroom helps cognitive comparison between real and virtual space and thus, creates memory-related to two specific spatial relations and conditions of material and digital attributes (proportions, dimensions, movement, colour, nature). This pedagogy, based on observation of perspective and real space, trains the gaze and cultivates design creation of the 3D environment on a techno-cultural level. It is a 'modernistic' approach to education to develop freedom and communication between students worldwide.

The aim is to provide digital tools to architectural students to serve co-operative digital learning, participation and collaboration. The "virtual classroom" can also be a digital tool to promote dialogue and cooperation during the design process as an open ground of expression during the educational process. Moreover, several classes (virtual rooms) are created for each purpose or to inform based on a specific geographical location.

The virtual environment can also be a place of critics or a faculty place where the students can discuss (forum) new architectural models, for domestic and urban life of the 21st century or even explore models of living under certain environmental conditions, e.g., life on Mars. This method can assist in exploring radical future, past and present visions for eco-conception for cities and rebuilding monuments. This architectural educational model can integrate transportation infrastructure into the future virtual urban fabric across multiple geometries and landscapes on a larger city scale and access by distance to several locational assets and information. This application engages the participants in a semi-immersive experience with a large screen projection.

Finally, this educational model was published in the e-book *Digital Civilisation: Where Trees Move*[24], presented in the Sapienza University of Rome, 2019 (Fig. 52).

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[24] Lioret, A., Dimitriadi, N., & Velaora, M. (2019). *DIGITAL CIVILIZATION, WHERE TREES MOVE 4th Multiplier event of @POSTASIS, Virtual Artistic Laboratory*. Retrieved 21 November 2019, from https://www.academia.edu/40687147/DIGITAL_CIVILIZATION_WHERE_TREES_MOVE_4th_Multiplier_event_of_at_POSTASIS_Virtual_Artistic_Laboratory

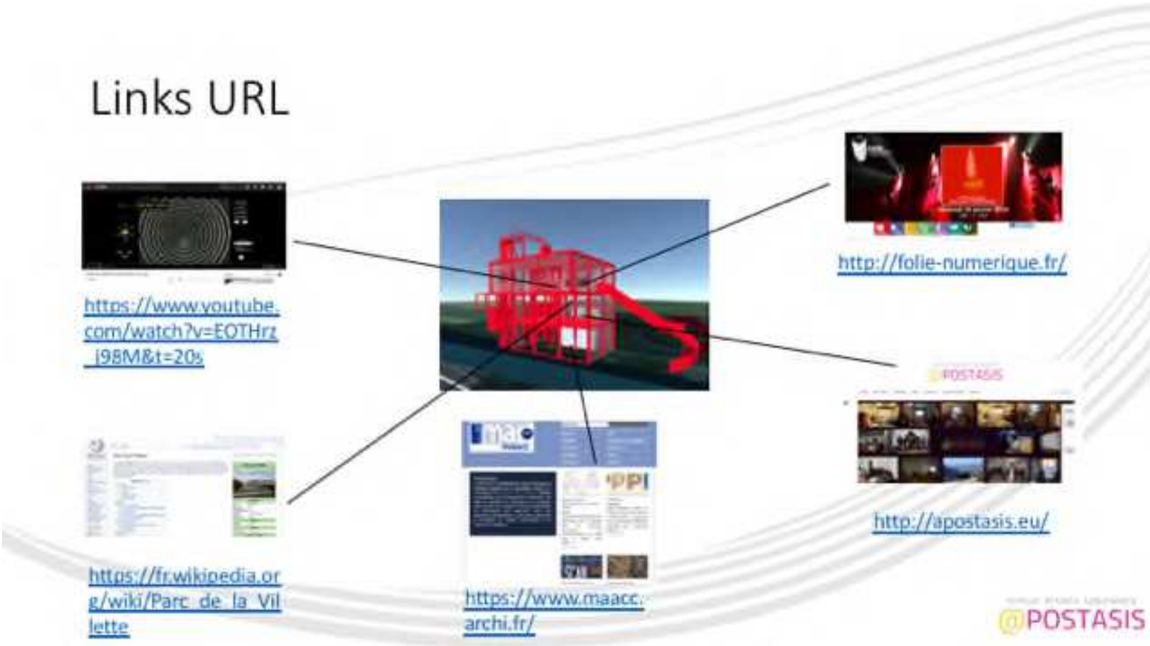

Figure 50. URL links attached to the virtual environment, directing the user to relevant information.

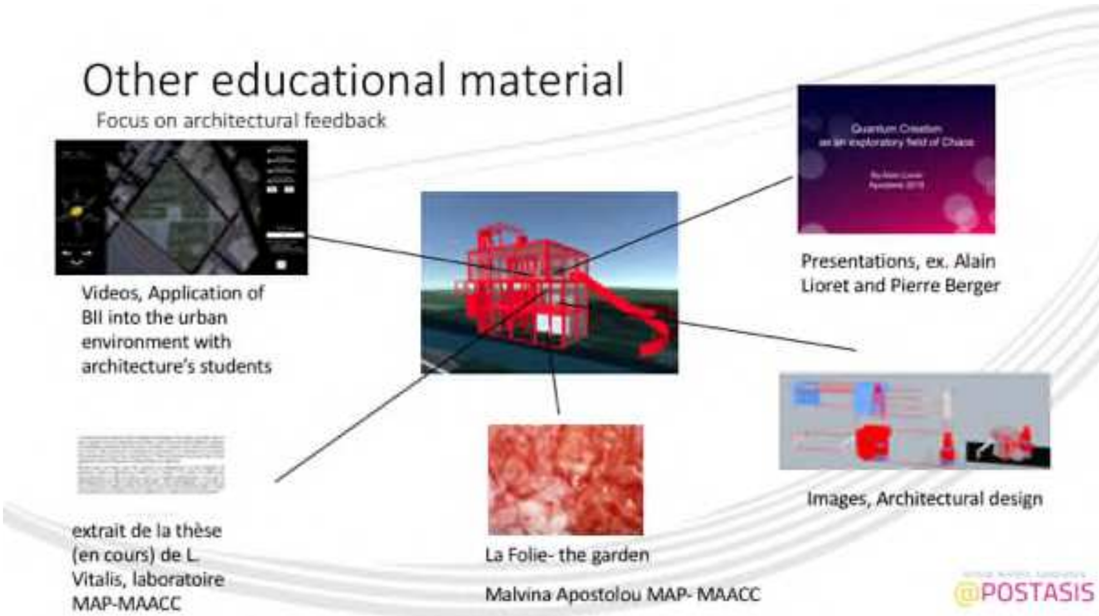

Figure 51. Educational materials attached to the virtual environment, directing the user to relevant information.

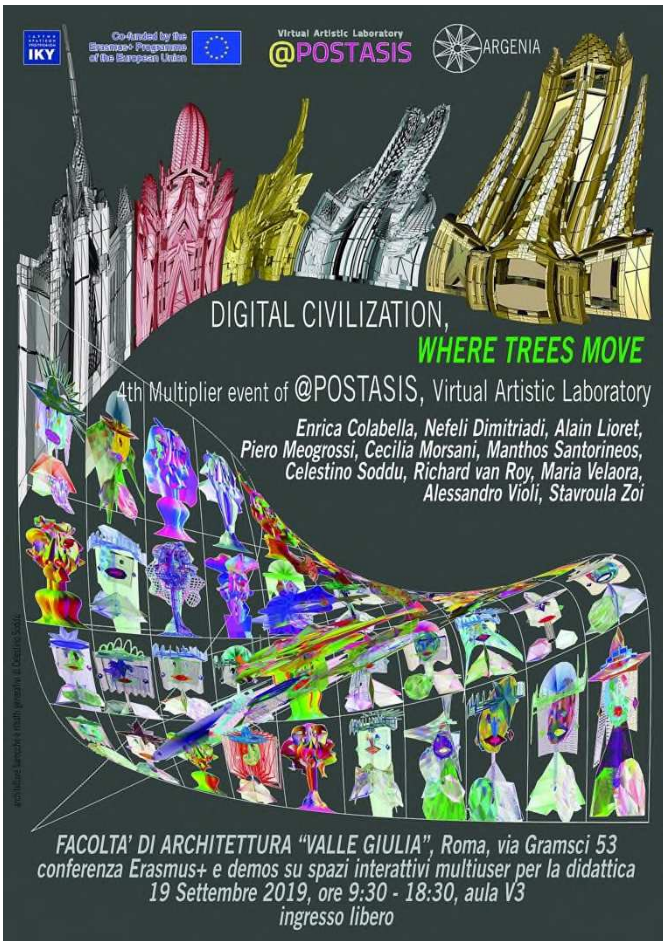

Figure 52. Cover of the e-book, Digital Civilization, Where trees move, 2019.

Chapter 7: Educational Model 2 - Behaviour Interactive Interface plugin

Explanation of graphic symbol:

In this experimentation, the physical environment and the virtual environment do not intersect as a representational system. The two environments are clearly separated by the screen (Fig. 53).

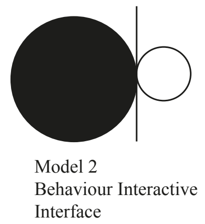

Figure 53. The graphic symbol of Educational Model 2.

Type: Simulated Reality, Game reality, Interface

Hardware: Desktop computers, tablet, projector

Software: Unity 3D, C#, Rhino, Grasshopper

Period: 2019

Place: University Paris 8

Keywords: *interface, interactive, simulated behaviours, virtual environment, navigation*

The scientific team[25] developed the open-source plug-in Behaviour Interactive Interface (BII) for virtual actors inside the EU Project, @ postasis : Virtual Artistic Laboratory, with Paris 8 University, 2018-2020.

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[25] Alain Lioret (Scientific Director), Calin Segal (Developer), Elhem Younes (Engineer of Research), Maria Velaora (Engineer of Studies)

For our experiment, we apply the beta version of the BII to generate interactions. We presented the plug-in in the Second Multiplier event in Eindhoven, Netherlands, on Mars 2019.

Digital tools can respond to several inhabitation scenarios on simulated critical situations such as evacuation plans and fire protection.

We developed a dynamic system based on chaos theory concerning randomness, complexity and movement in the virtual multiuser environment, allowing interactions between virtual actors (objects, NPCs which are the empty virtual agents). Using BII, the learner sets conditions of movement and interaction (‘behaviour’) to virtual actors of the digital environment.

The Behavior Interactive Interface allows users to set conditions (behaviour like) to any object (3D or 2D) and transform it into a dynamic entity. BII is designed to facilitate behaviour set up by users without the need to write a script. The interface user can choose actions (functions) from scrolling menus to assign them to objects or virtual characters. In the multiuser system, every virtual actor can have a specific behaviour that will interact with other characters with different designated behaviours.

7.1. Development Objectives

The application refers to the insertion of simulated behaviours characteristics.

- "mise en scène" of imported simulated behaviours in the virtual environment. (implementation and prototyping)

This plug-in gives the possibility to assign 'behaviours' to virtual objects in a simulated digital environment by giving values to functions and creating conditions inside the virtual space. We design the urban characteristics of a selected area for implementation and set functions to objects as behaviours with control conditions of distance, collision and time.

By influencing the object's behaviour (by size, hierarchy, function, movement), virtual agents' patterns of occupying virtual space become strategic interactive linkages between the design and living space. Thus, the pattern design aims to generate events manifested by forms of interaction and visualise a pattern of inhabiting 3D virtual environments and simulate critical scenarios of inhabitation.

In a virtual environment, the design imposes that the environment is created to provoke surprise and challenge the participant; therefore, the virtual environment participates in the dramaturgy of the digital experience (Fig. 54, 55, 56, 57). The design sometimes includes intentional obstacles to push the learner abilities towards the exploration of the virtual environment. In parallel, architectural space as game space allows the user to instantly recognise the *navigational patterns* (Larsen, 2006) and develops fluidity in the experience of discovery. Similarly, to how the game developers design and prototype virtual space and level design in an interactive form (Totten, 2014), we intergraded elements that require spatial perception to experiment with several 3D models. Therefore, tests with BII were conducted towards the two following directions:

- Conducted tests with different 3D environments (Navigation Mesh)
- Conducted tests with behaviours to apply to navigation map (different values)

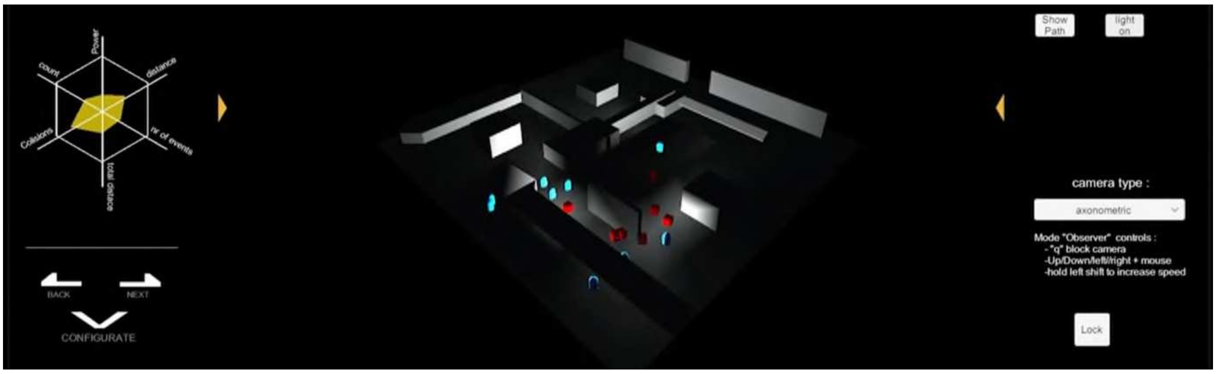

Figure 54. Screenshot of Behaviour Interactive Interface tutorial, Axonometric.

Figure 55. Screenshot of BII tutorial, Actor's behaviour in a 3D environment of vertical and horizontal obstacles, night view, BII, Plan, 2019.

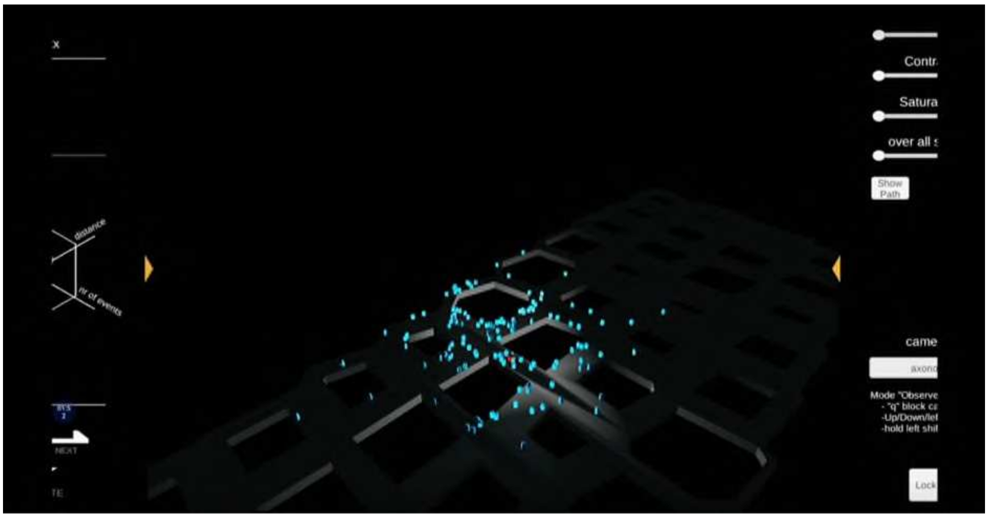

Figure 56. BII Tutorial, Observation, Virtual
actors' behaviour in an urban-like environment,
Axonometric, Voronoi Geometry, 2019.

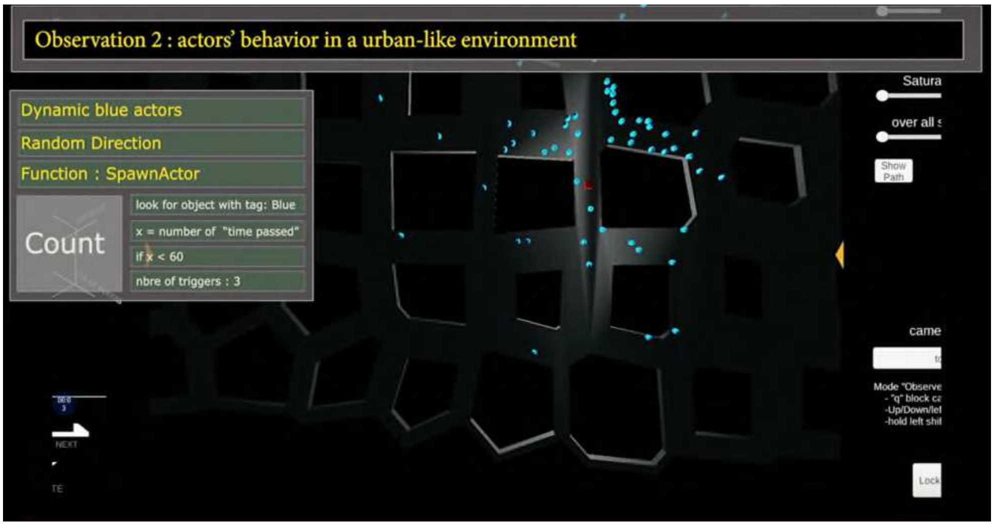

Figure 57. BII Tutorial, Virtual actor's behaviour in an urban-like environment,
Plan, Voronoi.

The user can change the different representation views (Top, Axonometric, First Person Controller and Observer) while on the play mode. Next, the user can set movement (random, forward, on the map) to the actors (3D objects) (Fig. 58). Finally, to generate behaviours, we set functions to actors (spawn, destroy, follow, increase) (Fig. 58) by controlling conditions related to proximity, collision and counter time of the actor. By setting behaviours to actors, the user can easily populate any virtual environment and create interactions among actors.

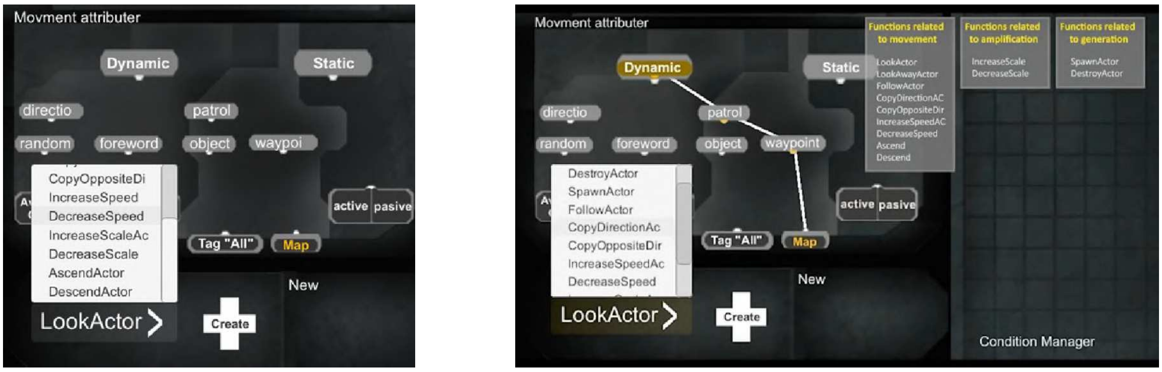

Figure 58. Movement Attributer, Behaviour Interactive Interface.

7.2. Implementation

For the demo's development, we use the software Unity 3D. We import the package BII, which is to be integrated into a version of the @postasis platform. However, we conducted the tests separately. The plug-in functions also outside the @postasis platform as an imported package for Unity 3D. The process of the virtual scene's preparation contains the following steps:

i. Implementation of the low-polygon models in Unity 3D. Low-polygon 3D models are proffered to increase the performance of the application.

ii. Setting Metrics to measure distance and time in the virtual environment can also benefit spatial perception and learning capacity.

iii. Define the navigational surface [can only be one (1) mesh geometry], where the actors can move.

iv. Set movement and behaviour concerns the conditions we assign to the virtual actors.

The experiment aims to expose cognitive operations for understanding dimensional 3D virtual space and its correspondence to real dimensions, from the virtual to the physical environment.

a) Navigational Mesh

This part of integrated methodology refers to the definition of the terrain of movement and interaction, the Navigation Mesh, as an one-piece surface (mesh). The Navigation Mesh represents the terrain of interaction or the 'game space', and it is the place where simulated interactions and virtual events occur in the 3D virtual environment. The virtual actors can interact through the behaviours' simulation interface.

b) Setting Metrics

In order to create a perception of time and distance into the virtual environment, we set a point of reference with concentric circles, from 10 to 100 meters radius, to obtain a perception of distance in the virtual environment visually (Fig. 59, 60, 61).

Figure 59. Metric concentric system for measuring virtual distance in meters, BII.

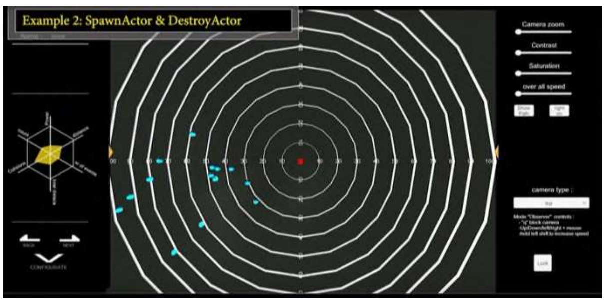

Figure 60. Setting metrics to Spawn & Destroy virtual actors, 2019.

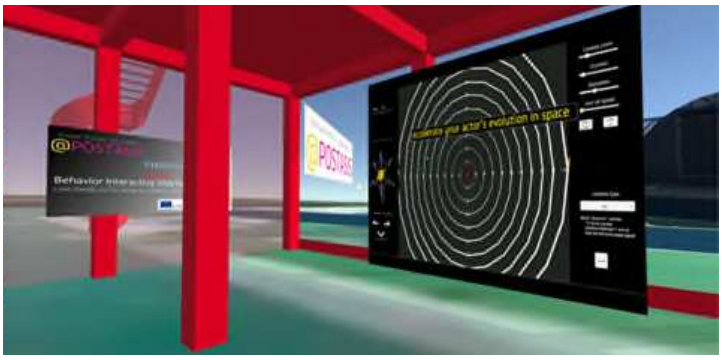

Figure 61. Virtual presentation of BII in the interactive
multi-user virtual environment of Folie N5.

c) Set actor's movement

The student defines a constant movement to actors as a common condition. The movement functions are the following:

a. Directional
b. Random
c. On selected path
d. Target (following a virtual actor)
e. Collide (when two virtual actors meet)

For our experiments, we use the random direction for actors (Fig. 62).

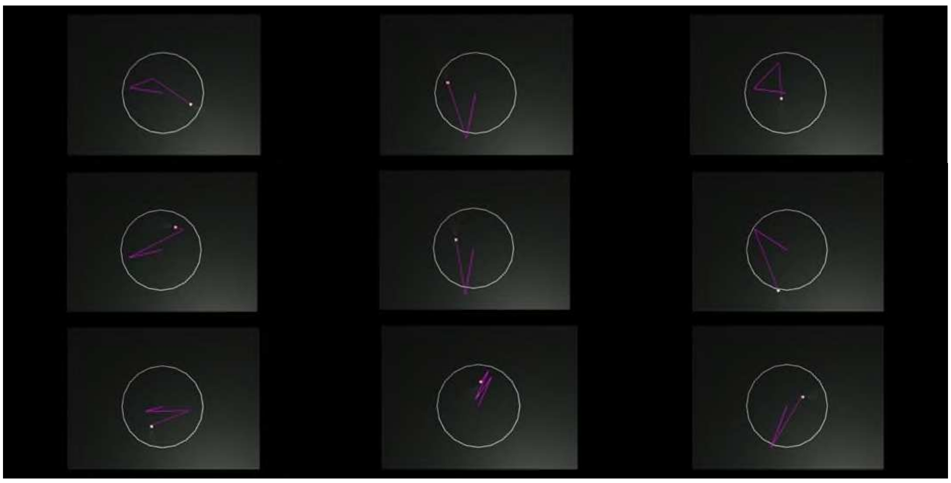

Figure 62. Setting actor's movement to random, for 9 times starting from the center.
Each time the actor heads towards another direction, BII, 2019.

d) Set Conditions to Virtual Actors

The Navigation Mesh is the terrain where we assign functions for virtual actors or virtual inhabitants. We use the interface to set conditions to the actors. The conditions are based on several functions. The functions for actors that we can experiment are : look, actors, look away actors, spawn actors, increase scale, decrease the scale, increase speed, decrease speed, destroy actor, copy direction and copy opposite direction. These functions are controlled based on proximity, collision, and counter time of the actor (conditions)(Fig. 63).

Figure 63. Behaviour Interactive Interface (BII), plug-in for @postasis platform for simulating virtual spatial behaviours.

For our experiments, the scientific team run 35 tests. We chose the test No26 (Table 3) and we apply the distance and count for random movement; we use only the spawn actor function. The spawn actor function multiplies the actor based on time and distance. Thus, this function permits to generate virtual actors, then populate and fill the Navigation Mesh.

Table 3. Extract from table of tests with red (RA) and blue actors (BA)

Behaviour Interactive Interface Tests

				Conditions			Notes
No	Tag V/A	**Movement**	**Function(s)**	**Proximity**	**Collision**	**Count**	
26	RA	Dynamic/Direction/random	Spawn Actor			red/time/12/10	→Overpopulation very quickly, Count/red/time/60/10 nothing happens Count/red/num/10/10 → Bug Count/red/num/20/10 → nothing happens → RA spawns itself each 53 seconds/ This action is repeated after +-53 seconds and is not multiplied by 3. (less then 60 seconds) count/red/time/60/3 → after 8 minutes still nothing happened count/red/nbre_of/12/3 → nothing happened count/red/distance/60/3 first spawing after +-52 seconds/
	RA	Dynamic/Direction/random	Spawn Actor			/red /time_passed /12/10	
27	BA	Dynamic/patrol/object/tag "all"	Destroy Actor	red/30/1			
28	BA	Dynamic/patrol/waypoint/map, Regular Speed : 1:15					→ chrono : 1:06 BA takes 7s less to travel the same path
	RA	Dynamic/patrol/object/tag "all"	Increase Speed	blue/99/1			
29	BA	Dynamic/patrol/waypoint/map/regular speed : 1:06 (based on last increase)					→ chrono : 1:06 Speed unchanged
	RA	Dynamic/patrol/object/tag "all"	Increase Speed		blue/1		

Figure 64. Public presentation of Behaviour Interactive Interface, at the Second Multiplier event of @postasis EU program, in Eindhoven, Netherlands, Mars 2019.

7.3. Evaluation of Educational Model 2

We presented BII at the Second Multiplier event of @postasis to a public of students in video games (Fig.64). For BII to become a meaningful plugin for architectural learning, it needs further development and tests. However, it is a start to evaluate the design (for example, for risky areas before the construction). It can be a playful tool to occupy virtual space designed by students in architecture. To some extent, we assign behaviours to materials through digital software and the BII functions as the plugin to perform 'virtual inhabitation', creating software for architects' decision-making.

The next educational experimentation refers to the application of BII to the Design Studio with architectural students.

Chapter 8: Educational Model 3 - Visit the Unbuilt, Virtually Real

Explanation of graphic symbol:

In this experimentation, the representation of the physical environment, which corresponds to the physical models of the architectural students, is included inside the virtual environment as a representational system (Fig. 65).

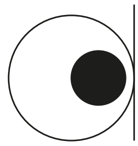

Figure 65. The graphic symbol of Educational Model 3.

Type: Simulated Reality, Game reality, Interface

Year: 2018-2019

Place: Paris 8 University - NTUA

Academic Framework: NTUA, Teaching Design Studio 9 - Paris 8, Engineer of Studies

Keywords: *interface, interactive, behaviour, scale, simulated behaviours*

The framework of the experimentation presents an educational digital example named "Visit the unbuilt." It is based on the 3D environment students' proposal. This experimentation suggests implementing meaningful interaction of virtual actors (agents) with the application of Behaviour Interactive Interface (Educational Model 2) for an urban-like environment during the Design Studio exercise. Our experiment was conducted for this research during the teaching work for the course Architectural Design 9: Urban Design under the subject "Social Housing" at NTUA, with the help of the students during the fall semester.

By applying means of immersion to the concept of scale, we use interactive visual representations to evaluate the efficiency of urban design proposals and verify the implementation of complexes' buildings into the urban fabric. Furthermore, transforming the virtual environment into a rapidly visitable and habitable environment is a way to augment learning capacity and self-evaluation for students during the activity of conception. Finally, the hypothesis is tested via an integrated method based on mixed reality media and architectural educational principles. This experimentation where we tested BII with architectural students was presented at the 7th symposium eCAADe RIS 2019 at Aalborg (Velaora et al. 2019).

8.1. Educational Objectives

This educational model proposes learning architecture based on prototyping digital reality experiences tailored to students' virtual environment needs. We use a combination of tools and methods from different disciplines, such as architecture, game design and informatics. The thesis hypothesis about the integration of virtual interactive environments in architectural education is tested on students within the course of 'Architectural Design 9: Urban Design' at the National Technical University of Athens, fall semester, 2018-2019.

We suggest using the demo plugin 'Behavior Interactive Interface' (BII) developed with Unity 3D with preset behaviours for virtual actors as a demo tool to evaluate the effectiveness of an urban design proposal, pointing and aiming in a 'decision-making' experimentation to promote self-evaluation of architectural design for the students. The integration of this method facilitates cognitive operations through the real-time multiuser environment during the process of learning. We expect to provide students with all the necessary new assets of reality's experimentation for their future professional life in a compact theoretical and practical educational package.

The exercise of the semester requires the creation of 180–200 residencies for 600–700 inhabitants by designing and integrating new neighbourhoods within the urban environment. Concerning an area of 14.000 square meters in Philadelphia, Attica, we set our navigational surface for the experiment (Fig. 66). The student group analyse the urban territory and propose an intervention strategy based on land use (commerce, housing, industry), the height of surrounding buildings, the width of roads, and natural and artificial landmarks. Moreover, it has to touch many different levels of analysis and design scale from 1:2000, to scale 1:100.

The design study transitions gradually from scales of 1:2000 to 1:100, with either drawings or physical models. The scales in which the exercise is analysed concern the conception of the urban environment (on 1:2000 and 1:1000), the volumetric integration (massing) of the building in the urban fabric on 1:500, and the landscape design 1:200 and also, the scale of the residencies on 1:100 scale. Overall, the exercise runs through 4 to 5 design scales and understanding and thus reveals the complexity of this architectural design project from local to suburban scale. The study is carried out on different scales, either with drawings or with 3D physical models in scale. The simulated area is easily explorable [a 1.4-hectare land (or 14.000 m^2)]. The area is big enough to be considered a surface of "playing the city" and creating interactions. We use interactive visual representations to evaluate the efficiency of urban design proposals and verify the implementation of complexes' buildings into the urban tissue.

The decision-making process for design is collaborative work. The goal is to reconstruct the city's tissue by implementing houses, respecting several cultural and functional rules on local and metropolitan scales. It is a cognitive activity of high-level complexity. The three factors, collaboration, participation, and immersion during the conception, add to the complexity of the DS process exercise concerning space and the relationship between spaces.

We launch an application to visualise the site's dimensions of implementation in immersive mode, give measures to conditions, and make observations in a dynamic virtual environment. Finally, the experiment includes using the 3D dynamic system interface for behaviours to help understand the concept of scale.

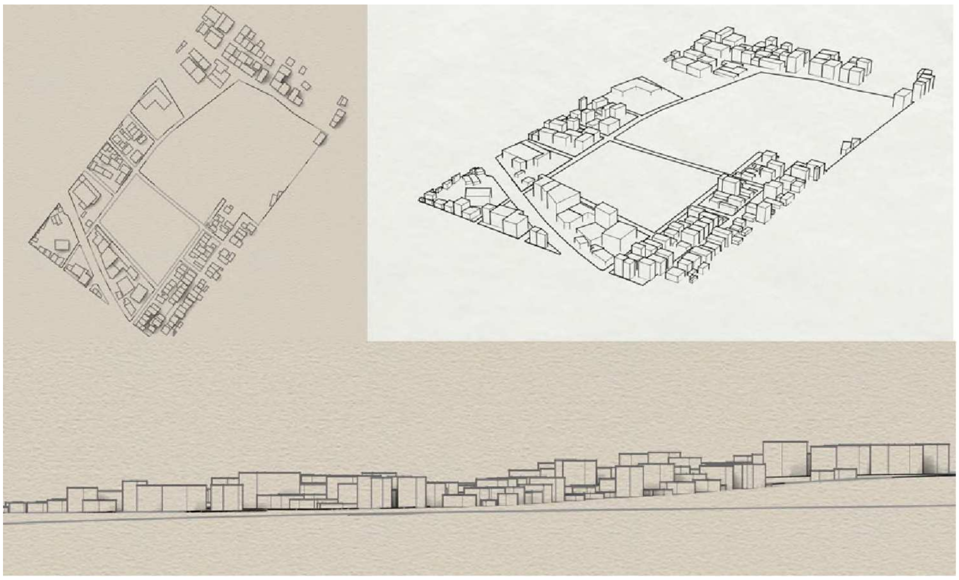

Figure 66. Plan and Axonometric view (above), Section drawing (below).
Site of implementation, DS 9 (2018).

8.2. Technical Requirements

The exercise chosen by the teaching team for the winter semester 2018-2019 had a slope that in a cross-section exceeds 9.5 meters (Fig. 66, below image). The teaching team gives the 3D model of the background in Sketch-Up file and Rhino. In the Sketch Up file, we have used the Geo-localization command to accurately have the 3D visualization of the relief (geographical anaglyph – topology) from Google Earth Pro. Then in the Rhino file, we open the file with the relief from SketchUp and place the buildings that we have taken from the student groups. Finally, using Grasshopper, we create an algorithm that will "drop geometry" and place it in the terrain introduced from Sketch Up without leaving gaps.

The specific landscape model (3D background composition) is suitable for entering the Unity 3D for further experimentation with mixed reality tools. We also provided a lecture[26] to the architectural students about the potential of Mixed Media Realities (VR and AR).

At the 1:500 scale stage, students are also invited to measure and integrate the dwellings and public uses into the study scenario. Movement and design are working together, such as the design of pedestrians and cars. They design private, public and intermediate spaces and suggest green areas. Students place their buildings on the site. The tutors emphasized the accesses of the movements, the difference between the axis and the grid, the scale of the road and the relationship of the width of the road with the building, the natural lighting of the apartments, the good orientation, the possibility of the variability of the construction and the materials that the student groups choose to propose for use (see: Chapter 4).

a) Define Scale for Experiment

The favourable scale of urban buildings' implementation for the demo is the 1:500 scale concerning abstraction levels. However, for the level of abstraction of detailing and scale about the ground floor (landscape), we chose the 1:200 scale.

We determine the 3D model of the virtual environment as a merge of two scales in detailing. The revelation of buildings' detailing is in 1:500, and the detailing of the ground is in 1:200 scale. During the Design Studio process, the emphasis is on the entrances and exits of buildings,

[26] https://socialhousingntua.blogspot.com/2018/11/9.html

the axis of movements, the structural grid, the width scale of the street, the relationship between the roads' width and the buildings' heights. Moreover, the natural lighting of the apartments, the orientation, the volume of the construction and the materials used are important aspects of design that the students are trained in and tested at the end of each semester. Finally, we set this virtual environment for our test to apply later the Behaviour Interactive Interface (BII).

We aim to manage to create a subjective experience of learning along with the "Social Housing Urban Design" course as we shift from the physical model of the geometrical space to the virtual representation. This is semi-immersive learning experience to create interaction within the virtual environment.

b) Reconstructing the course

Special emphasis is placed on both the building and the public outdoor area and its configuration on a scale of 1:200. Planting trees on the site of implementation adds to the local development of the area. Often, during the synthetic process, the role of planting is overlooked at the expense of local–urban configuration, as it contains more sculptural elements. In the future, it is necessary to set up a digital library of specific trees (see: Chapter 10) that will be addressed to the architectural students and teach them the shading characteristics and the volume occupied by each tree.

Finally, our teaching proposal about simulated behaviours managed to be intergraded during the design studio regarding the enrichment of the methodology of architectural conception. In the end, the participants were asked to evaluate their experience.

c) Navigation Mesh

In our case, this mesh represents the 14 hectares real site of implementation in Attica. Therefore, our surface must be *one single mesh* (Fig. 67), as one 3D object (as mentioned in the Educational Model 2).

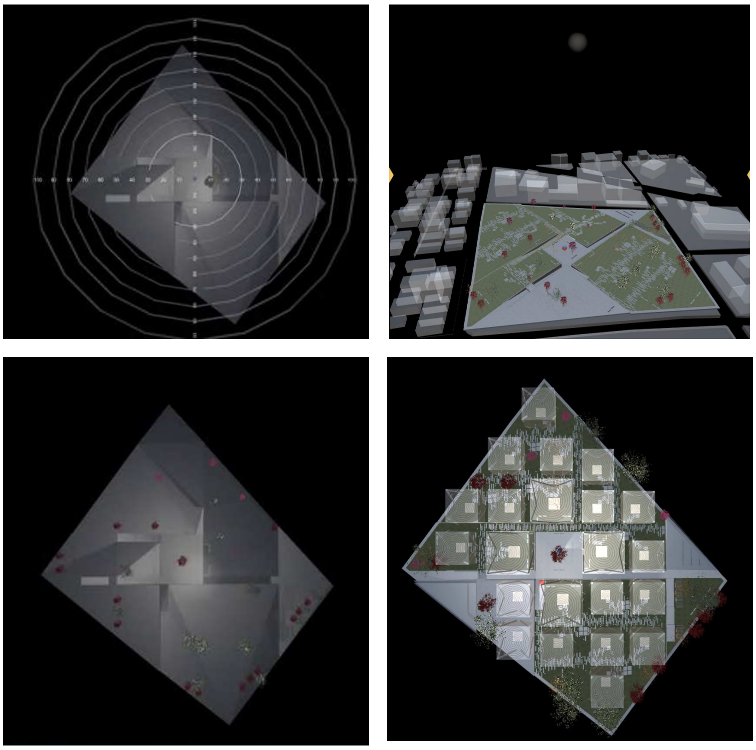

Figure 67. Set Metrics and Navigation Mesh.
Combination of scaling details.

When the students were asked if they preferred a more realistic representation of the environment (Fig. 68) or an abstract one, they chose the abstract representation. It seemed closer to the representations of physical models with cartons (Fig. 69, 70), also to CAD representations (Fig.71b).

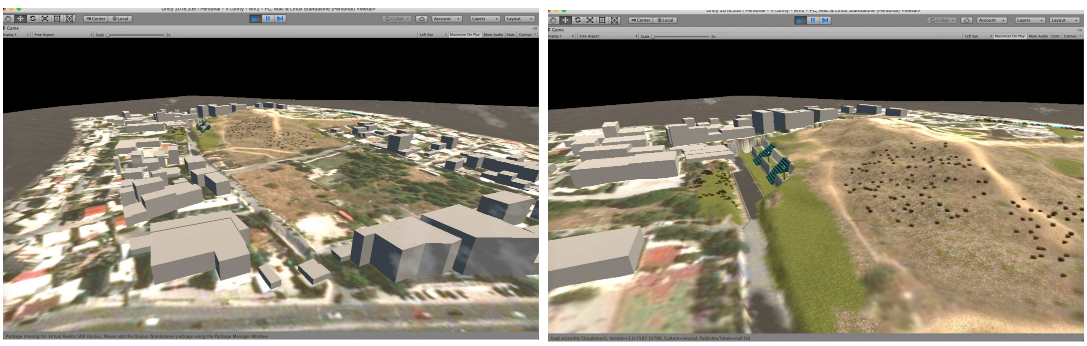

Figure 68. Virtual environment of site of implementation with "realistic" graphics, Unity 3D, Occulus Go VR.

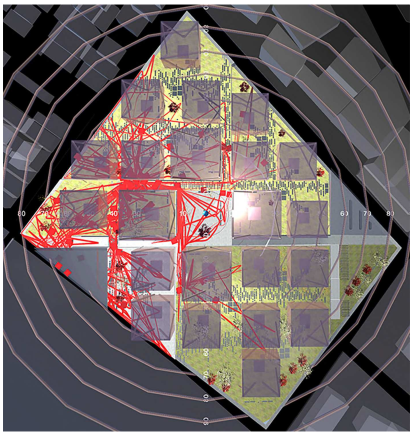 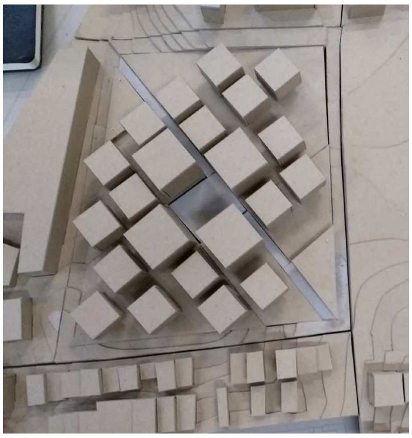

Figure 69. Populating the virtual environment. From physical to virtual. A case study of designing social housing exercise.

Figure 70. Physical model in scale 1:200 (right).

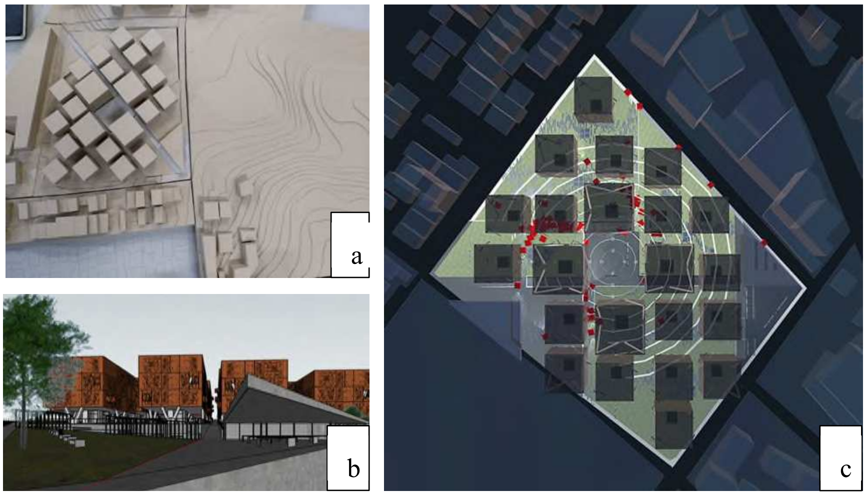

Figure 71. a) Physical model in scale 1:200, b) Perspective view in virtual environment of 3D modelling CAD, and c) Simulating virtual population by applying BII in an interactive semi-immersive virtual environment, 2019.

This demo application is approached as an interactive digital tool for architects and urban planners, which means that it is not "a model in design neither a model for designing".

This application is an educational model for learning about design and evaluating it and not learning to design. It is suggested as a knowledge model on design activity and as a self-evaluation tool via the virtual environment.

We created a graphic representation of the place (location) for instant visualisation and immersion based on the concept of "living into the unbuilt", likewise an unbuilt architectural proposal. It gives the possibility to visit unbuilt architectures that for economical or technical factors had not been realised at the time of their design. The aim also is to expand innovation by examining and visualising existing knowledge. Moreover, by "inhabiting the unbuilt" and simulating vivid representations of simulated reality, apprehension of the latter is enhanced on a cognitive level, even revealing unintentional design patterns.

Furthermore, the first-person view from the inhabitants' perspective allows students to develop their perspective and transcend their own cognitive or preconceived notions of their creation. Besides, design patterns enable the students to extend their understanding to different scales of their urban designs and help experience cities and their environment in different layers, dimensions and scales.

Therefore, the methodology to test this hypothesis can be represented as a layering logic for the learning process (Fig. 72). The intention in design follows the act of designing, which is the decision and gesture of drawing. Once a first drawing is placed, we question the spatial perception in terms of scale. Our method then implies using game engine software such as Unity 3D or Unreal to implement the first 3D sketches. Lastly, once the implementation of the 3D models in the virtual interactive environment is established, we set conditions (values) and movement to virtual actors through the Behaviour Interface. Then, the learner re-evaluates the initial 3D sketch by obtaining feedback related to virtual inhabitation and proceeds to the next design steps. This process is also a mental and a visual immersion to the virtual environment, transforming it from static to dynamic and interactive. This implication with the digital space is a method that demonstrates the process from design to decision.

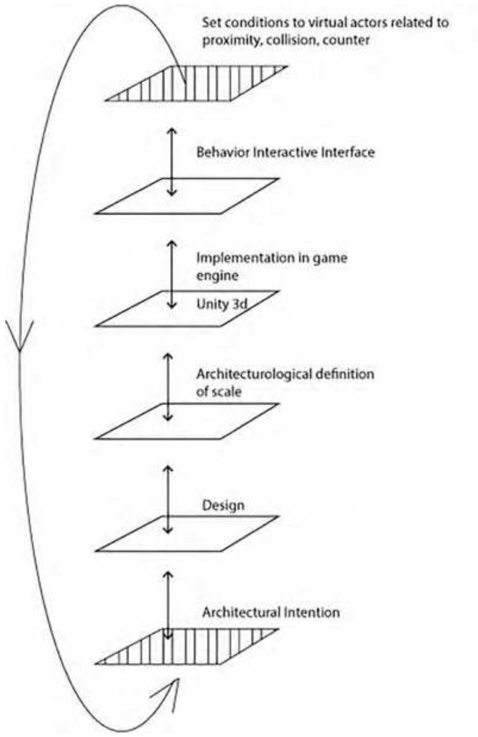

Figure 72. Layers of analysis for applying BII for an architectural 3D environment.

Interaction with dynamic objects that simulate actors' behaviour in the virtual environment permits researchers, architects, and students to observe simulations of possible situations in urban planning, such as emergency cases, and evaluate the urban environment's proposals. This experimentation provides an additional perspective and method of feedback to the student's urban design proposals, supplementing traditional education with virtual agents.

Our experimentation demonstrates an example where a tool further evaluates the effectiveness of students' design by measuring the adaptations of their design due to interacting with the tool. We aim to progress to compare the educational models that emerge from distant collaboration and design.

The results expected by the researchers refer to the evaluation of the use of MR's effects in students' learning capacity, with the definition and recording of the transit between real and virtual conditions, in correlation to the cognitive transitions from one design scale to another. The researchers expect to have definitive tutorial proof of their first hypothesis. Henceforth, the disengagement of constantly producing physical models and the possibility of low-cost immersive or semi-immersive experiences, as there is no need for the materialisation, offer important benefits in terms of visualisation, creativity, and cost for the architectural students.

8.3. Evaluation of Educational Model 3

We gave a specified questionnaire (Annex 1b) to students who participated in the experimentation.

The participants, when interviewed, mentioned that the BII interface is not as intuitive as expected. Still, it reminds the logic of other 3D software for architects as Rhino and Grasshopper (procedural software manipulation). Though, the experiment permitted them an independent opinion about their conception in real-time. They realised that dimensions represented by 3D software in general (including BII) are slightly distorted, especially in terms of perspective. The impression from the First-Person Perspective was that dimensions were "smaller" or "more compressed" from what they had conceived (Fig. 73). Afterwards, during the Spawn Actor example exercise, they reconsidered some of the dimensions applied to their models, such as the width of paths and the height of entrances, as they could design it larger for more fluid pedestrian movement and to value public space.

The application of digital tools allows the presence into the virtual environment as virtual actors and helps cognitive operations, improving understanding of scale in the urban environment. The association of architecture with game design principles facilitates the comprehension of notions related to different superposed layers of urban spatial correlations as a dynamic system. It can be beneficial for architects' skills based on feedback during DS. To play with 3D models and different scales, "[…] and to apply sciences of artificial can become a way of questioning architecture" (Lecourtois, 2011). Playing with the notion of randomness, based on digital means of interaction, becomes an individual conceived cognitive activity for design, and thus a possible architectural space. Plus, the architectural mindset and game design notions can enrich this conception, with Mixed Reality means to "qualify" reality with more expressive and representative ways (Lecourtois, 2011).

Suppose we could ever combine an application of architecture fundamentals with mixed reality (MR) media and precisely the concept of scale by defining criteria based on interaction and immersion in virtual environments. From this merge or convergence, as we prefer the term, we obtain educational space where 3D models of the architectural design studio process are tested under similar conditions. By defining a scale or a combination of scales, our proposal enhances the possibility of conceiving the urban environment as interactive and eventful, hosting all possible life scenarios. The digital environment receives visualised interactions of virtual actors (agents) that reveals information about architectural design, such as proportions and dimensioning for the first-person controller (FPC).

The set-up of this experimentation is presented in two multiplier events (Paris and Eindhoven) and one conference (Aalborg, Denmark). With the use of an interactive application that we developed as an educational model at the service of urban design, we analysed and prepared scenarios of virtual inhabitants at the site of implementation.

Moreover, we present the stand-alone application of BII in architectural environments as a first attempt to evaluate the efficiency of architectural design under given regulated conditions. Digital applications and machinery are tools that can transform the real environment and offer interpretations about the perception we can obtain about it. 3D modelling, the method of setting virtual scenes and space syntax analysis, can help Design Studio students to insert elements that modify spatial relationships in a way to suggest constructive or deformative ideas with the use of game-engine software.

Experimentation through digital creative environments permits continuous navigation of the learner, and the movement offers increased immersion as it trains memory. This type of tool assists the urban scale comprehension and transition of intermediary spaces during design also, it can help to cultivate orientation over a given site of building implementation. The decisions concerning, for example, the choice of materials, the lighting, the volume and the proportions all are factors that can easily be evaluated in an environment designed to produce an actor's "movement". However, this digital space is designed as an environment where the designer and visitor may interact.

The course emphasises the First-person (FPC) and Third Person Controller options as different points of view and perceptions of movement in the interactive virtual environment. We insert digital movement to the controller to create a dynamic system of digital co-existence in a multiuser real-time environment. These factors of perceiving 3D space, in the form of a 'game' designed application, increases awareness about design and space. The digital behaviours emerge as a superimposed layering pattern, from where designers can extract different decisions about design through merging cognitive operations about the design area.

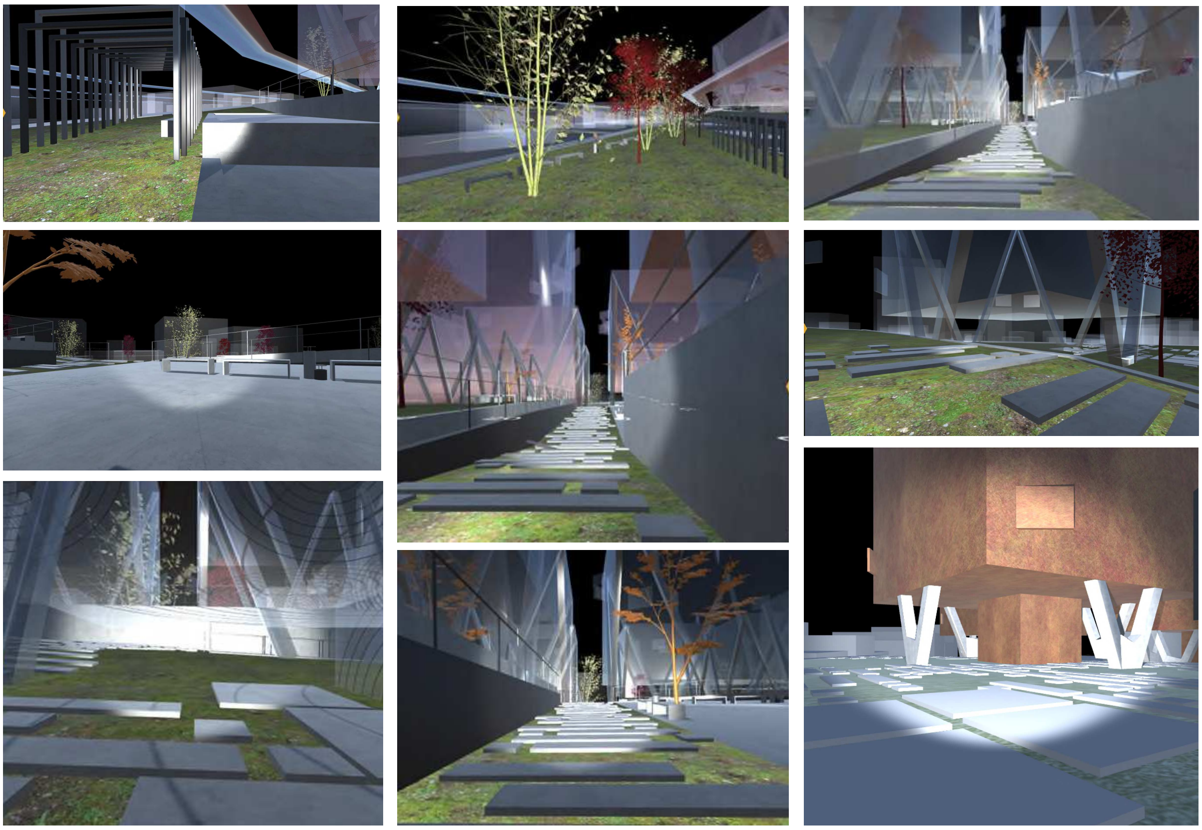

Figure 73. Virtually Real, Visit the Unbuilt, First Person Controller view.

Chapter 9: Educational Model 4 - Pixel People, Data Parcours

Explanation of graphic symbol:

In this experimentation, the virtual environment is connected with objects of the physical environment as a representational system (Internet of Things) (Fig. 74).

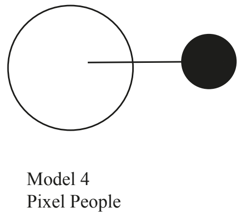

Figure 74. The graphic symbol of Educational Model 4.

Name of project: Pixel People

Type: Augmented Reality GPS application

Urban visits in a smart city with Augmented Reality

Year: 2019

Place: Eindhoven, Netherlands

Framework: In collaboration with Mad Emergent Artistic Centre

Keywords: *Teaching, architecture, city, augmented reality, GPS, interaction.*

The learner first acquires ‘landmark knowledge’ (Whyte,2002), recognising the patterns and characteristics that identify specific key places of the city.

Description

The digital AR application 'Pixel People' is developed for MAD Emergent Art Center and the Stichting Slimste Woning (Smart House) (Fig. 75) in Eindhoven with the participation of the MAP-MAACC laboratory in Paris. This application that we designed and developed is a location-based type of escape game in AR, where the escape room is the city of Eindhoven.

The envisioned methodology assists learning architecture through urban visits with the assets that augmented reality media provide. The educational objective is to explore new approaches and describe courses to eventually integrate mixed reality experiences into architectural education.

This application is designed for portable devices and combines the physical (real) environment with the virtual 3D model. The superposition of the two concepts of realities was necessary to suggest an emerging method about learning architecture via AR applications in this mixed reality system of digital and real components.

Figure 75. Smart House, Eindhoven, NL.

9.1. Concept

The *Pixel People* application was developed with Unity 3D software for digital tablets and concerns an augmented reality visit to Eindhoven City via a selected route.

With the help of a code, we managed to relate specific GPS coordinates to 3D objects that can appear on the screen. We focus on the First-Person (FPC) perspectives from different points of view. The maps' perception of movement is visualised in the virtual immersive environment and related to the user's physical movement.

We created *augmented reality scenes* that correspond to specific points of interest and spatial elements of the route (buildings, roads, landmarks). In certain locations, the user receives information about the physical environment, such as the quality of the air, and is asked to respond to a Multiple-choice question in order to pass to the next point of interest. The scene varies according to the designed interaction at each location point, and the user interacts with cameras at specified points (waypoints) within the city, as well as with buildings (landmarks). Finally, there are two auxiliary maps in the application that help the participant's orientation.

This experience aims to explore the use of digital realities to create new emerging practices adapted to the teaching of architecture with augmented reality. We have collaborated on developing this augmented reality application that, although not directly intended for teaching, could be easily adapted to future needs for teaching.

The Pixel People concept is designed to visualise data flow in the urban fabric through AR with tablets to a specific route (sequence of waypoints). This application is conceived as an "escape game", obliging the participant to answer questions at each location to discover the next during the visit.

The scenario is about a hacker named Jackson (the user profile), who has to "unlock" specific locations points of the route which are 'deactivated' in the first place. The narrative for each location (waypoint) is predefined and tells a story for the place in the form of a pop-up text. The scenario of the game is that the user has been hacked and the application starts collecting personal data such as email address, age and gender. The aim is to finish the route so at to retrieve the data back or destroy them.

In this approach, the participant develops a dialectic with the city to retrieve data and proceed to the following location. We believe it is possible to receive inspiration and technical knowledge from this experience to suggest an architectural teaching methodology location-based with interactive visits. This educational model that we developed emphasises the relationship that architects have with the city and outdoor space and enhances observation of the surroundings.

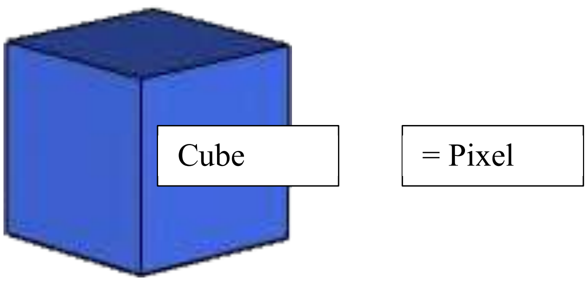

Figure 76. Graphic presentation and Concept of data visualisation.

For the AR application of Pixel People, we create an analogy between a pixel and the 3D virtual cube. We represent pixel by cubes of 1meter (Fig. 76).

These “cubic pixels” visuals (which theoretically contain data) indicate the direction of the chosen route to the user. These 3D pixels show the path by their density, colour or movement. They act as a living organism in the augmented environment as far as their density is affected by the distance of the point of location reference. Finally, the cubic pixels form an augmented net above the city of Eindhoven, able to narrate the essential historical references of the town. The main goal is to immerse the user into the augmented route in a virtual imaginary architecture made of cubes and live the experience as Pixel People.

The application in Augmented Reality is made of five augmented reality scenes (locations) with Unity 3D. Each scene corresponds to a different geographical location. There is also an augmented digital map of the city to assist the visit.

Pixel People's participant group has consisted of ages between 25-65 years old. During the three tests carried out, it appeared that young people seemed less aware of the dangers it brings than the older generation, who appear much more sceptical and aware concerning the risks of data treatment. One of the main goals of Pixel People, as an AR location-based experience with the city, is to increase attention and engagement in spatial observation, raise awareness about digital realities, and inspire motivation through the emergence of approaches that augment the perception of urban environments.

Pixel People Itinerary - Specific Features

- Route length: 1006 m
- Time walk: 20 min

The route in Eindhoven is almost 1km, and the walking duration is approximately 20-25 minutes (Fig. 77). According to the applied scenario, there is a circular walk (loop); the participants return to the starting point at the end of the route. The route is defined by several distinct locations and landmarks of Eindhoven architecture. The number of participants for this guided tour does not exceed 15 people. Each participant has at his/her disposal an electronic tablet with the Pixel People application installed. According to the scenario, the user adds his/her identifiers to start the visit. Then, the user is hacked by the application, which starts collecting the user's data, such as the email address and age, as mention in the scenario.

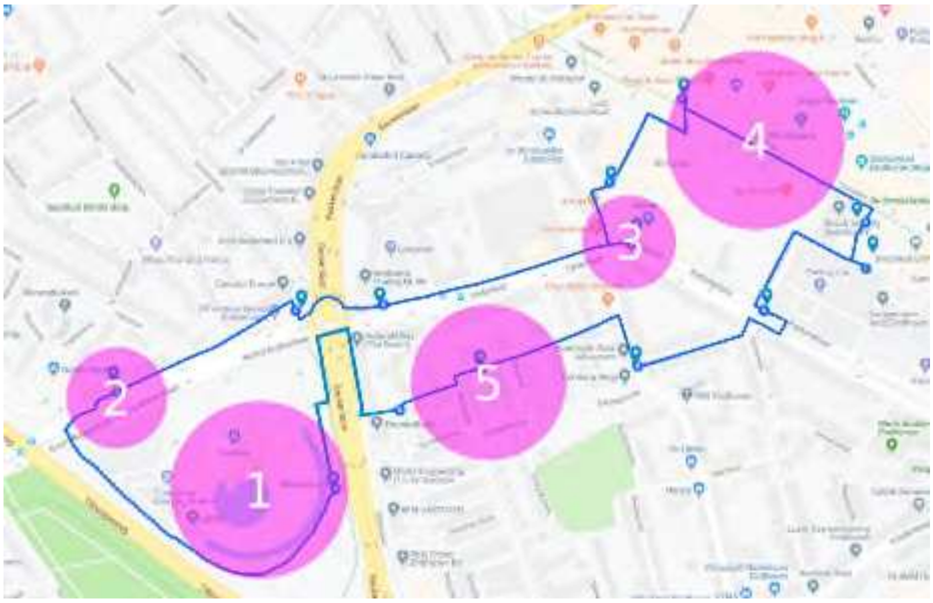

Figure 77. The Pixel People itinerary, Eindhoven (2019-20).

The Pixel People route consists of five locations. These are the spots where the mini map would start to show some information about the location. Analytically, the locations:

1. Evoluon

   The Evoluon is a former science museum designed by Bever and Kalff. A box is placed here that measures amongst other things the air quality of this location as open data. It is possible to follow this information live.

2. Lighting Needle

   This is a landmark with artificial lighting.

3. Natlab

   This building was the research laboratory of Philips where many important technological inventions were made.

4. Strijp-S

   It was one of the more important factory districts of Philips that now has been turned into an area housing with many experimental and creative companies.

5. Open-air

   It is an example of an open-air space.

Points of Interest and pop-up messages

The route passes through an area with a great historical importance to Eindhoven. When passing through the radius of a location (Fig. 77) of interest the mini map in the corner of the screen appears to capture the attention of the user. When this mini map is pressed, a pop-up message with the information of this location appears (Fig. 78).

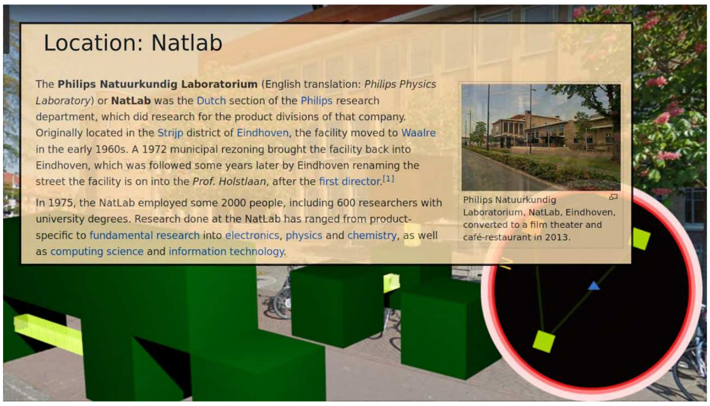

Figure 78. Pop-up message and mini map in AR.

9.1.1. Geographical locations and digital content

The locations (waypoints of interest) of the visit are geographic places with specific coordinates that correspond to the physical urban space. In this phase of the experiment, there are five locations as presented below analytically:

1. *Building « Evoluon »*

51.443144, 5.448634
51.443426, 5.448675
Beukenlaan, 5651 GW Eindhoven, NL

The building Evoluon is the starting point of the visit where according to the scenario, the participant is being hacked "theoretically" (Fig.79). This building is a former science museum designed by Leo de Bever and Louis Christiaan Kalff and is one of Eindhoven's most iconic structures. The smart house, which is found next to Evoluon, was involved in the design of this project. In this location (Evoluon), with a sensor box, 'data node', which is found outdoors, the participant has access to values regarding air quality (visualised data) on the tablet. In order to advance to the next location point, the user must answer a question correctly relative to the environment and the air quality ingredients.

Figure 79. Evoluon Building, NL.

2. *Lichtnaald (Light Needle)*

51.444867, 5.449058

Beukenlaan 77, 5616 VC Eindhoven, NL

The second location of the visit is the Lichtnaald Tower, which means "Lighting Needle", in the Dutch language. This landmark is fabricated with many RGB LED lights (Fig. 80). The lighting tower is located at the centre of the highway's roundabout in a prominent location from a distance, considered reasonably one of the most characteristic landmarks of Eindhoven. Based on the Internet of Things, the Pixel People application is developed to control the tower lights giving the user the possibility to interact directly with the tower's lights. Using a colour slider, the user can change the colours of the lights in this tower in real-time. Thus, the participant interacts directly with the city on a local scale with a visible effect of the lighting.

The interaction with Lichtnaald occurs through a digital slider of the application that offers the possibility of expanding the users' relationships with real objects and landmarks in the city (Fig. 81).

Figure 80. Night and day light view (left), Visit to server about LED lights (right)

Figure 81. Colour Slider and concept of interaction (left). Cone Geometry, Grasshopper geometry and Augmented Scene for light control set up (right).

3. *NatLab*

51.444043, 5.448379

Torenallee 64-72, 5617 BD Eindhoven, NL

It is one of the popular locations in the history of Eindhoven. It was Philips' laboratory where many important technological inventions were made. Several cameras are placed at this location: the application controls one of these. The participant is invited to show his/her face to the camera; the application contains a facial recognition algorithm and stores an image of the participant to move forward to the following location on the route. The participant recognized the locations of interest by the cubes that appear on the screen as indicators for the route (Fig. 82).

Figure 82. Data visualisation concept for NatLab.

4. *Strijp-S*

51.450968, 5.456779

5651 GW Eindhoven, NL

Strijp-S is a former group of Philips factories that are now being used to test new technological ideas. Here, the participant encounters an audio installation inspired by urban sounds and words in different languages (Fig. 83). Next, the user interacts with the sound installation.

Figure 83. Data visualisation concept for Anton, Strijp-S.

5. *Pixel People Open-air*

51.445816, 5.457912

Glaslaan 2, 5038 CC Tilburg, NL

This is the final location of the route where the user is directed to a floating digitally augmented maze in the natural environment (Fig. 84).

It is an ample open space next to the Strijp-S building. Before and during the visit, the application collects information about the participant as mentioned in the scenario of the escape-game (such as email data, facial recognition, voice recording). The last point of the visit is an augmented reality labyrinth where the personal information appears projected on the AR walls (as shaders). The player must target and destroy ('shooting game' approach) the data that appear on the virtual cubes (Fig. 85).

Figure 84. Digital Content Concept for Pixel plein.

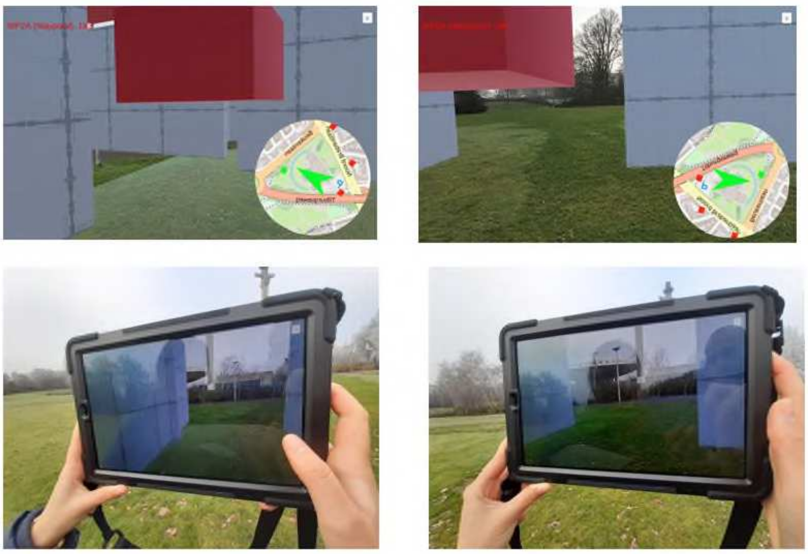

Figure 85. « Destroying » Data in Pixel People open-air space.

9.1.1. Pixel people’s maps

The application contains two minimaps for the participant's orientation. The first map shows the location of the augmented objects, and the other shows the participant's position, based on GPS location.

a. *A minimap of the route*

This map shows the location of the augmented virtual objects and the distance from the participant’s position as the user progress in the mixed reality experience. The user completes all levels of the *Pixel People* experience when unlocks all the location levels of the route in the city. When the user arrives at a waypoint, the colour of the location switches from red to green.

The map helps to perceive the urban environment as it visualises the entire route consisted of the locations. The map is integrated into the app from the *Open Street Maps* (Fig. 86). Its scale of representation is calculated in order to be able to contain all objects without scrolling.

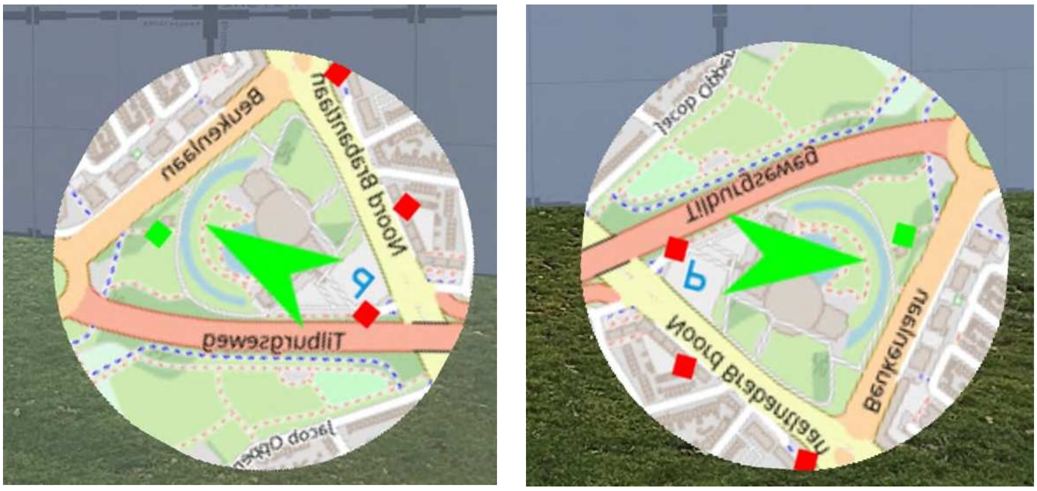

Figure 86. Mini-map of the route.

b. *Participant's minimap*

This is a map that shows the user's position in real-time in the application interface. This map is a digital compass, using the tablet’s gyroscope and GPS location (Fig. 87). The user's position is in the centre of the map, helping the user maintain a connection with the location and the physical environment to move towards the next location. The nodes (locations) represent the interconnected nature of the city's digital landscape.

An abstract map made of a network of interconnected nodes and is visible to the user. The main augmented locations become brighter in colour when the visitor passes the given task at each location. This map is centred around the user's position, along with the pixels, the map helps the user to orient towards the next location. The web of nodes represents the interconnected nature of the digital landscape of the city.

When the player reaches a location, the node turns green and reveals the direction that the user has to take in order to finish the game (Fig. 87). This map demonstrates the progression of the user at the locations that visits.

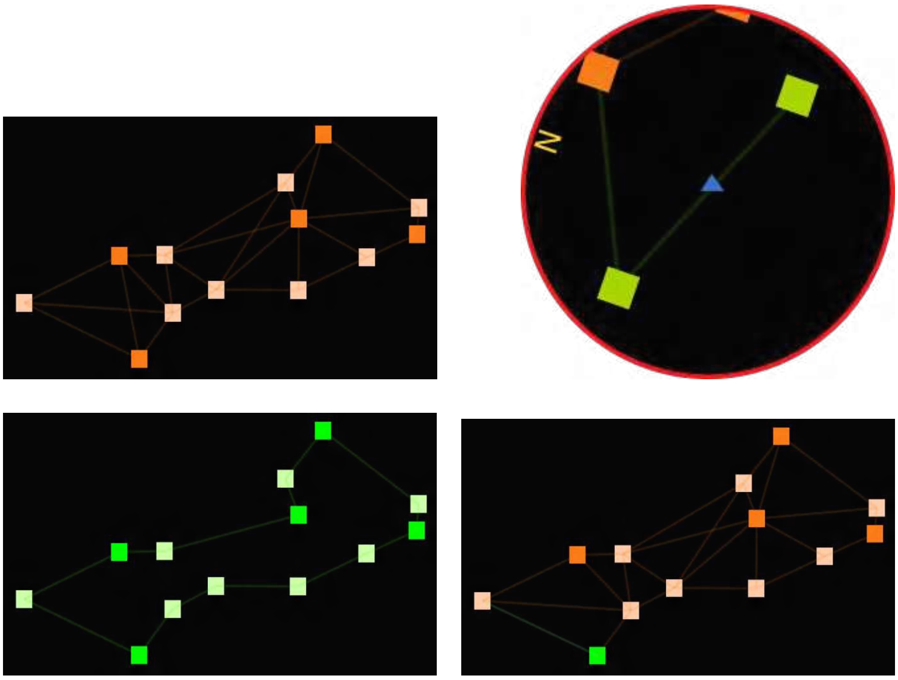

Figure 87. Digital compass and map. The locations that are visited become green (activated).

The two maps are merged is in the form of a mini map in the right bottom corner of the screen.

9.2. Implementation

During the *Pixel People* experience, the user interacts differently at each location. The goal is also for the user to experiment with various types of interaction. The interactions must be meaningful and give the participant a purpose to continue.

To sum up, we developed interactions through shaders, colour sliders, facial expressions with 3D objects, sound, and connection on the web. Also, there is the interaction with the multiple-choice questionnaire, which follows the designed scenario (narration and space).

1) AR Location Script

In the initial phase of creating the Pixel *People* application, we tested the AR plug-in - GPS *Location* for Unity 3D. This plug-in allows augmenting the real scene with virtual objects positioned concerning the GPS coordinates. Based on this script, the Mad Emergent Center team developed with the collaboration of the MAP-MAACC laboratory a tailor-made script, the *AR Waypoint Script*, a script based on coordinates that we can assign multiple times for the development of the application. The AR Location script allows to assign 3D objects to GPS locations as it appears in the flowchart (Fig. 88).

2) Function

The development of the script is based on the principle of assigning 2D/3D digital objects to GPS locations in the city. These locations are defined in advance by a value that represents the radius around the locations. On 'play' mode, every five seconds, the application's script calculates the user's GPS position and checks if it is within the radius of the digital object. Then, every second, the application calculates the object's position using the device's GPS and compass.

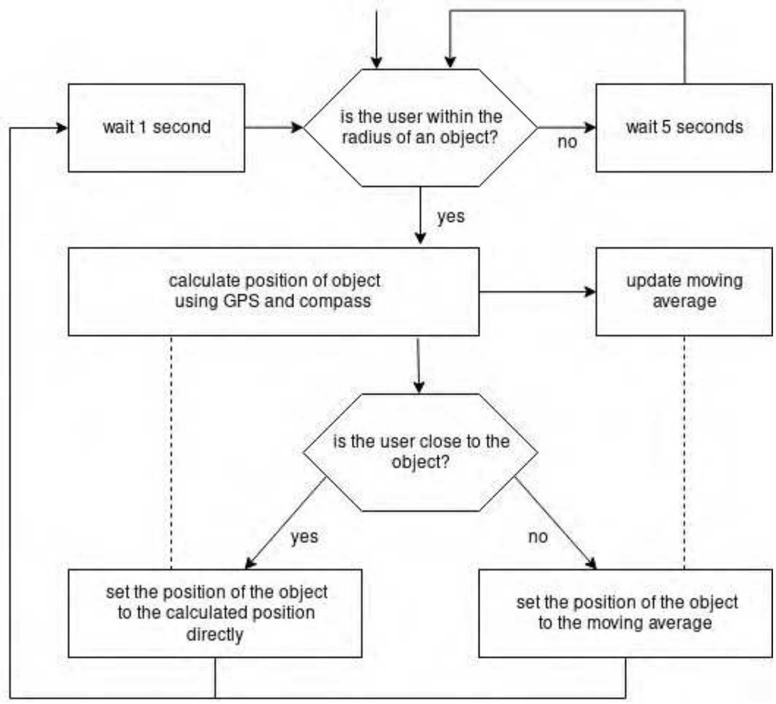

Figure 88. AR Location Script Operating Flowchart applied in Pixel People, 2019.

3) Precision

The devices at our disposal do not allow us to obtain GPS position accurately enough because the radio waves of GPS satellites bounce off high buildings. Every second, the GPS position changes even if the user remains still. The actual and accurate position is closer to an average of location values. The more the user of the application stays in the same position, the more accurate is the calculated position.

Since the participant's GPS position changes at all times, we had to optimise the code to stabilise the digital content on each chosen location.

4) Optimisation

It is possible to place the digital object using the average of GPS measurements location (coordinates). However, the problem is that it takes time to collect and process enough values close to the precise position. We overcome this problem by placing augmented objects in the virtual scene in two steps depending on the participant's distance to the augmented scene.

If the user is still far from the location and its digital content but within the radius we define, the object is positioned directly using the GPS position set in the application. The object presents a slight 'bouncy' effect, but it is not visible because the object is still far from the participant's eye. In the meantime, the average position is collected. When the user approaches the augmented object, and the instability of the object could become troublesome, the object is not positioned using the GPS position directly, but by using the average position as indicated in the plug-in's operating flow chart (Fig. 88).

9.3. Educational Objectives

From antiquity, with Aristotle's peripatetic *school* to the five points of Le Corbusier's modern architecture, the notion of movement, as an urban promenade, is very present in the teaching of architecture. *In* Greek, a route means a walk to saunter, a concept close to Baudelaire's *flâneur.* Later in the 1960s in France, the Situationist International (Sadler, 1998; Andreani, 2017) spoke about the *derive*, as one's movement model in the urban environment, which includes elements of surprise and curiosity. The learner is immersed into the build environment by creating a mental construction about the form of the city. Visit, itinerary, drift, peripatos (in Greek), dérive (in French), are all words and concepts that express the importance of walking in learning architecture.

Our goal is to reuse the principles of *Pixel People* to architectural design (3D modelling and informatics development) and describe an educational tool perceived as a digital and physical interactive dialogue with the city. Equipped with a similar tool of design with augmented reality, the architectural students can explore the city and discover certain locations suggested by the tutors.

The teacher's role is to prepare the points of interest for the visit. The aim is to define the different stages of the design studio process, to inspire learners to discover several digital materials (text, image, video, sound, 3D models) related to each location. The application offers location-based game experience with various spatial set-ups in order to increase perception about the urban environment and possible uses of the public space.

We consider a tool for architectural studies with 3D sketches in-situ for project correction.

In learning architecture, the architectural proposal of each group of students must be well integrated into the urban tissue, and the correction refers to the building design and its placement on the site of implementation.

The *AR Location Script* plug-in developed for Pixel *People* allows designing a decision-making platform in augmented reality to implement the project on the site. The 3D sketches of students modelled in 3D software, as virtual environments can be inserted in AR supported media and visualised with the real environment. Furthermore, *AR Location Script* provides a basis for developing a learning tool for architectural design, where the actual city is used as a background canvas to evaluate students' proposals.

9.4. Results from educational model 4

It is possible to adapt the principle of *Pixel People,* presented above, to create educational applications for the teaching of architecture. The pedagogical objective is to train the student's gaze in the city from a real-time dialectic.

We presented an application of augmented reality and interactive tour in the city of Eindhoven. This experience inspired further research for the development of the next and last but not least educational model for architects based on AR.

The aim is to show that it is possible and it can draw inspiration from the possibilities of digital applications to design as learning machines based on different versions of Mixed Reality media. Pedagogical tools for learning architecture with AR visits and the correction of architectural projects in situ can be further explored in workshops to assess their deeper limitations.

We claim that the possible use of digital technology: the *augmented visit,* perceived as a digital and physical dialogue with the city, can benefit architectural students in terms of spatial perception. *Pixel People* is a cultural and urban experience that we can apply to the educational process as additional feedback (awareness and dialogue). The points we draw from this experience are:

1. Developing a real-time interactive digital experience in the city.
2. Visit with an emphasis on different urban spaces and interactions.
3. Articulation of new learning processes in architectural design.
4. Developing artistic creation through the digital environment.

The aesthetic of the digital landscape merges the natural urban landscape with the digital content. *Pixel People* based on GPS location in Eindhoven is an experience that brought to design the next educational model, the software ARtect. This experience was the inspiration of the *ARtect,* an application of Augmented Reality CAD, destined for architectural students. We exhaustively developed the application with Unity 3D as a suggested digital instrument within the framework of this thesis.

Chapter 10: Educational Model 5 - ARtect

Explanation of graphic symbol:

In this experimentation, the representation of the physical environment converges with representations of the virtual environment as a representational system (Fig. 89).

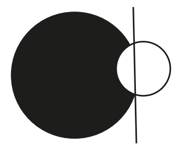

Figure 89. The graphic symbol of Educational Model 5.

Type: Augmented Reality, Game reality, Interface

Software: Unity 3D, Clojure, SketchUp

Technical Support: Tablet, mobile

Year: 2020

Place: Paris

Educational Framework: Thesis project

Keywords: *Augmented reality, architecture, education, design, digital application, 2D graphic, 3D models*

ARtect is a digital AR application for architects, designers, researchers and artists. ARtect is designed to assist 3D sketches activity in situ (Velaora et al. 2020). The main feature of this application is that the user can place virtual 3D objects in real-time based on the GPS coordinates of mobile smart devices (smartphone or tablet).

The tool provides the ability to visualise AR 3D models in an outdoors and indoors environment. At the same time, it contains 2D images, e.g., images of trees (sprites); thus, we can create simulations for planting the city, for example. The user-friendly interface can help young designers to mimic the completion of a building implementation in the area before construction. The logic behind this application is a constructivist puzzle-based idea with cubes (like a 3D Tetris in AR, Fig. 90). However, the learner can import multiple custom-made 3D models.

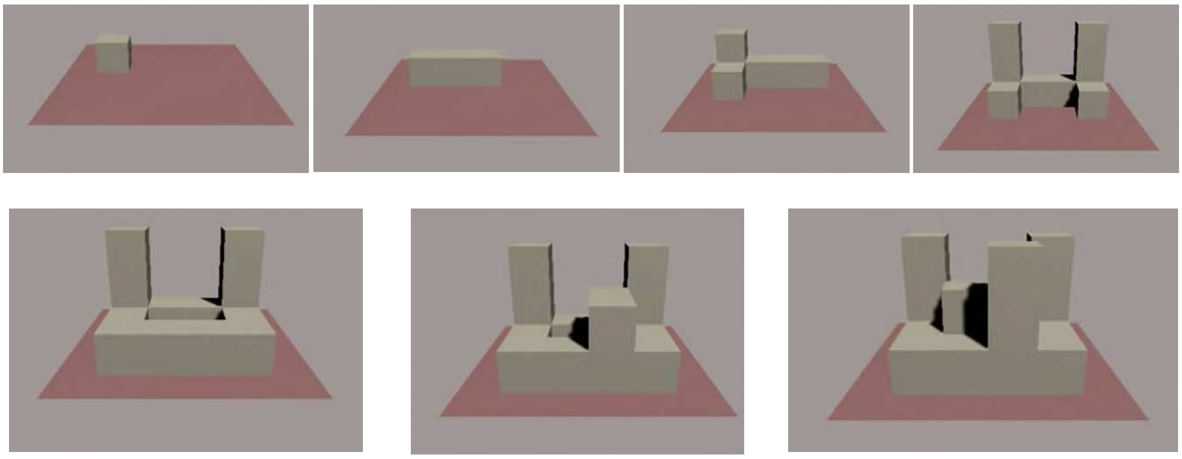

Figure 90. ARtect's constructivist logic.

The learner modifies the architectural model in real-time with various commands such as rotation, scale object, move and make precise distance measurements between augmented digital objects using a measurement tool. This application aims to bridge the gap between AR and VR approaches, as the user can "lock" or freeze the geometrical digital model in a specific location and be able to walk through it. The architectural student obtains the entire picture as the 3D model, becomes a panoptic 3D model that the learner can observe from all views. Finally, the architect can decide the proportions, materials, and uses of spaces in 360^{o}view, in situ. This digital tool permits the learner to temporally locate the projected design in the possible site's implementation.

ARtect is an Augmented Reality application developed with Unity 3D and envisions an educational interactive and immersive tool for architects, designers, researchers, and artists. This digital instrument renders the competency to visualise custom-made 3D models and 2D graphics in interior and exterior environments. The user-friendly interface offers an accurate insight before the materialisation of any architectural project, enabling evaluation of the design proposal on a 1:1 human scale. This practice can be integrated into learning architectural design, saving resources of printed drawings and 3D carton models during several stages of spatial conception.

This project inscribes into the RnD (Research and Development) project since it took many coding skills, and we had the technical support by programmers.

- Hardware

The application is compatible with Android and iOS devices supported by Google ARCore [27].

- Software

In order to accomplish the goal of placing various separated virtual objects onto the real world, the demo is composed of an AR application (client) and a web service platform (server). The mobile application (client) and the online platform (server) are developed using *Clojure*, a dynamic and wide-purposed programming language.

10.1. General objectives of restructuring the course

The ARtect project is conceived as a digital prototype for architects and design studios.

The purpose of this tool concerns the educational practices of architecture within the digital realm and particularly with immersive tools. We developed the demonstration of ARtect, as a digital prototype and proof of concept to expedite the architectural design and spatial perception in real-time and on-site. ARtect's name derives from Augmented Reality (AR) and the word "architect".

We observed that traditional tools for architects such as drawings and models offer a limited experience regarding the sensory perception of space and the architectural design during studies in architecture. In addition, several cognitive biases affect perception in terms of visual representation since the perspective of space itself is connected to scale factors.

To overcome these difficulties, we claimed that architects need immersive tools to immediately contact real-site factors with and without the physical models on the scale required.

The novelty of this work focuses on training the architect's gaze to experiment with models in real-time, on-site of different environments, landscapes and landmarks during the

[27] Google Developers. https://developers.google.com/ar/discover/supported-devices (accessed Jun. 12, 2020).

initial design stages. By placing objects and modifying the scaling factors, the students obtain feedback about the credibility of the design's implementation related to the real scape. We aim to contribute with an immersive augmented reality tool for architectural design. ARtect aims to develop creativity and expression during visits on-site with students of architecture. The user experience includes:

1. Creation of an AR scene by placing multiple 3D models and 2D graphics in real-time, via a personalised library, on geographical locations (indoors and outdoors).
2. Manipulation of virtual objects in three axes (x,y,z).
3. An immersive walkthrough in the 3D AR scene.
4. A measurement tool in AR permits the calculation of distances by drawing a line on the scene.
5. Snapping Objects.
6. 2D and 3D scale function in the AR scene.
7. Export of the 3D scene.

10.2. Impementation

The ARtect interface is a user-friendly, digital environment, and students in architecture require no extra knowledge in informatics. The interaction comes through the touch screen of a smartphone or a tablet. The user needs a compatible Android/iOS portable device, and the tutors install the ARtect software. There are two possibilities of using the application: the user augments standard geometries (e.g., a cube) and the setting where the user uploads custom-made 3D models and 2D graphics to create an augmented reality scene.

Analytically, the two modalities of use are:

1) Standalone setting

In the standalone mode, the interface provides the standard geometries, a cube, and a sphere. In addition, it offers an empty AR scene ready to host a constructivist learning environment (add, remove, modify objects) for the user (Fig. 91). The learner can modify (move, rotate, scale, copy) the prefabricated standard geometry and use it as an augmented construction unit. Furthermore, the user can select the measurement tool to calculate horizontally, vertically and in-depth distances between two selected points (Fig. 92).

2) Online Platform setting

The Online Platform permits uploading custom-made 3D models and graphics and then downloading AR scenes made by the users. For this, the user needs a laptop with Internet access. First, each student creates a personal profile and logs in. Using the personal profile, the participants upload their ideas online and then create an AR scene anywhere, using the inserted spatial elements, through the application. For example, architectural students can transfer virtual objects such as buildings, trees, urban equipment to the digital library, and participants may use multiple virtual objects in one scene.

The content of the AR scenes belongs to the user.

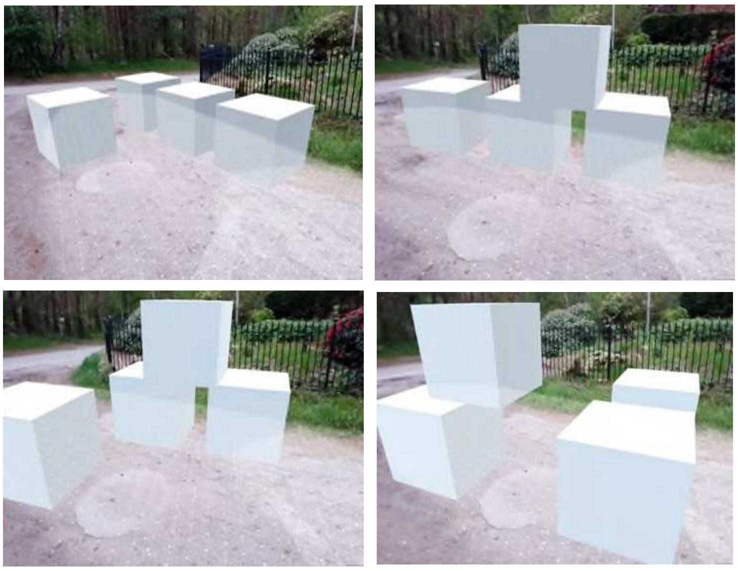

Figure 91. Basic functions of ARtect educational model experiment (move, rotate, copy).

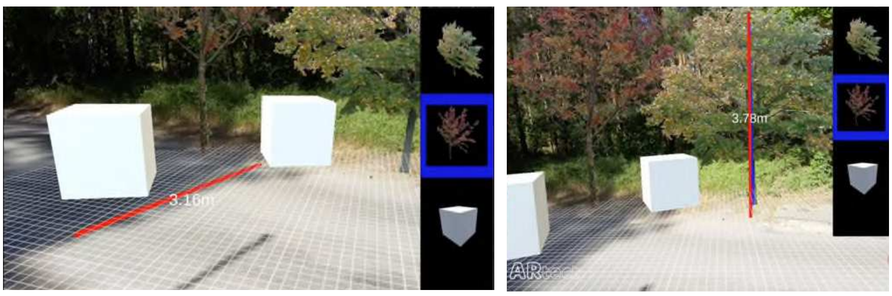

Figure 92. ARtect's Distance Tool in x,y,z-axis.

10.2.1. Ease of Use and Interface

We describe the ease of use in 5 steps, as presented in the application and service flow chart (Diagram 9).

1. AR Grid Configuration

Once the AR camera of the portable device is activated, the user can start the scene configuration. First, the utiliser points towards the ground to scan and detect a *flat* surface in the physical environment until the AR grid appears. When the grid appears, the application is activated. This grid anchors the objects to the ground and permits the application to "know" precisely where to place each virtual object (width and depth).

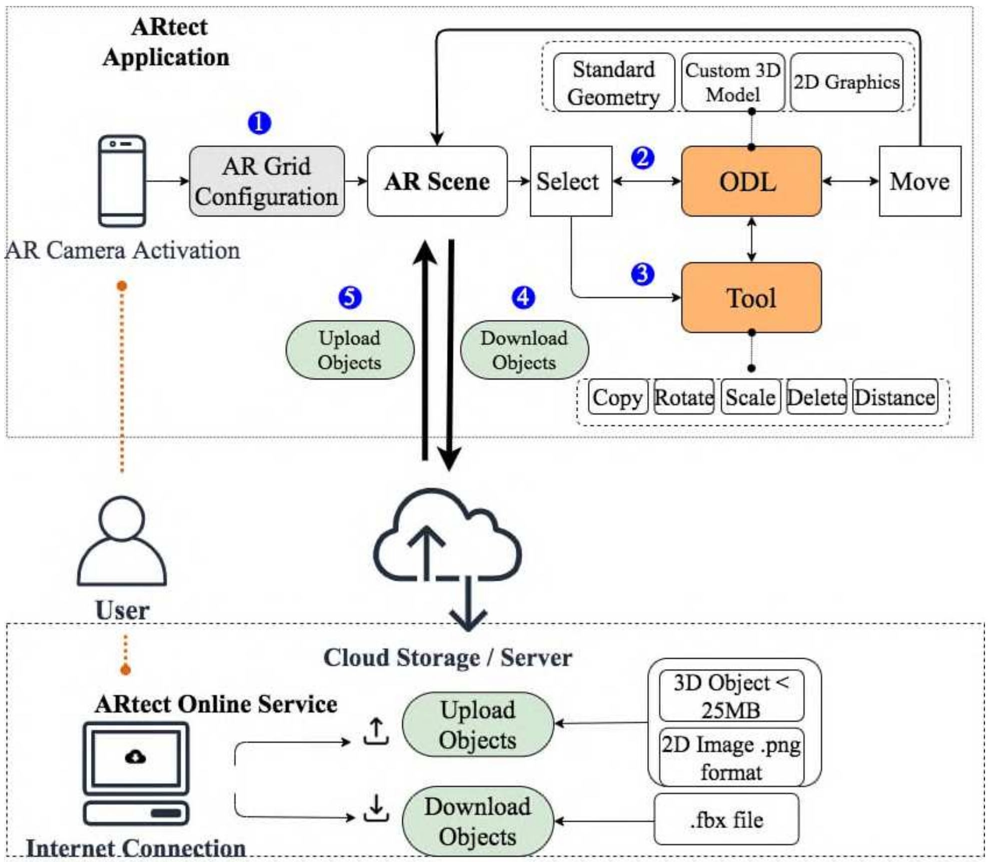

Diagram 9. Flowchart for ARtect application and service, 2020. ODL: Online Digital Library.

2. Object Digital Library (ODL)

The interactive interface of the application contains the Object Digital Library (ODL). Through the ODL, the user selects an object with the touch screen and drags and drops it in the scene. The ODL is compatible with 3D models with the format .obj and .fbx, which many 3D modelling software support, such as Rhino, SketchUp, and 3Ds Max, which architects use. Also, the digital library collaborates with images in .png formats, such as the images of the trees.

3. Toolbar

The interface gives the possibility to modify the 3D/2D imported virtual objects. This toolbar exists to adjust a virtual object on the digitally augmented environment and change the scale and the object's orientation. It includes the following functionalities: Move, rotate, scale, copy, delete an object, a measurement tool, screenshot and a hide-interface button (Fig. 93). The functions select and move objects occur through the interactive touch screen of the tablet.

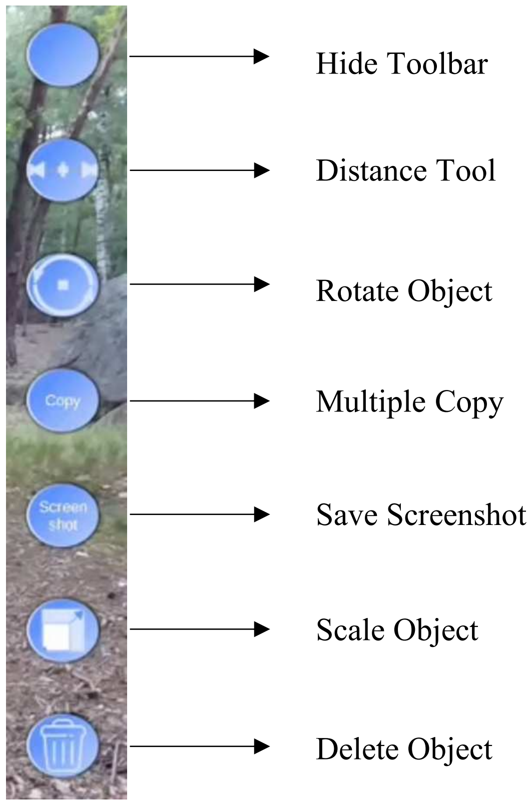

Figure 93. Toolbar, ARtect, 2020.

4. Download Environment

The Object Digital Library is connected to a server that stores the objects on the ARtect Online Platform (cloud). The user can save and export the AR created environment to the personal cloud profile. In addition, the user can download the models once created on-site to a laptop/desktop, which can be further edited in any 3D modeller. This asset allows architectural students to create 3D spatial content directly on the real background at the initial brainstorming stages and edit it later at the design studio.

5. Upload 3D/2D Virtual Object

Via the ARtect online service, the user can upload custom models and images. The application automatically updates the virtual objects to the application's library, appearing on the application's interface. In both cases, standalone and eased by the online platform service, AR scenes of the application can be stored on the personal user profile on the online platform.

Manipulating 3D objects in an AR digital environment is challenging since the 3D environment of the real environment is superimposed with the 2D environment of the screen. Several limitations appeared, such as obtaining a 6Dof experience (Degrees of Freedom), into the AR scene. As several pieces of research have shown, the placement of a virtual object onto the augmented scene and the free movement of this object within the three axes (x, y, and z-axis) with precision presents a fundamental difficulty. Also, lighting and orientation limitations were among the topics that the development of the AR prototype had to surpass to create an interactive instrument for architects. Ultimately, the selection of each object with the touch screen setting had to be improved since it can appear less accurate than the mouse input. The specificity of the functionality of this application that focuses on architectural design and visualisation led to a tailor-made domain-specific language (DSL).

The steps taken to overcome particular technical issues are the following and, therefore, the adjustments of the software:

a) The ARCore grid provided by Google met with some limitations, which resulted in overlapping grids. We overcome this constraint by estimating different heights of the ground. Extract from the code regarding the solution.

```
(defn combine-grids
 "Combine vertical overlapping grids"
 [detected-grids]
 (mapcat #(when (vertical? %)
           (if-let [overlap (overlaps? % detected-grids)]
           (combine-grids % overlap) %)) detected-grids))
```

b) In order to overcome the difficulty in movement in the z-axis, we introduced a vertical virtual plane that is created at each imported on-scene virtual object. The user uses two fingers selection mode in order to move the virtual object vertically. Extract from the code regarding the solution (Fig. 94).

```
(with-cmpt vertical-plane [tr Transform]
 (set! (.-position tr) (.. object transform position))
 (.Rotate tr (v3 90 0 0))
 (set! (.-parent tr) (.-transform plane))
 (cmpt+ plane AlwaysFaceCamera)
```

```
(defn move-object
  [obj point vertical?]
  (with-cmpt obj [tr Transform]
    (if vertical?
      (let [pos      (.. tr position)
            tr       (.-transform (first (children obj)))
            collider (cmpt obj BoxCollider)
            y        (.. point y)
            new-pos  (v3 (.-x pos) y (.-z pos))
            center   (.. collider center)]
        (set! (. tr position) new-pos)
        (set! (.center collider) (v3 (.. center x) (.. tr localPosition y) (.. center z))))
      (set! (. tr position)
            (-> point
                detect-height
                ground-level
                snapping)))))
```

Figure 94. Scripting the placement of virtual objects in z axis.

- Online Platform Cloud

The online platform allows users to upload 3D models as .fbx or .obj format files with a maximum size of 25MB. Internally, the server automatically converts the uploaded models to Unity 3D prefabs to facilitate architects who are not Unity 3D users.

The features of the platform are:

- The objects' dimensions are converted to meters.
- The pivot point of each object (0, 0, 0) is recalculated to be at the basis of the object to allow correct rotation and placement on the scene accurately.
- Conversion of any material/textures that are not compatible with mobile devices.

The converted objects are automatically saved to the personal cloud profile and become available for use via the application.

10.3. Evaluation of Educational Model 5

This experiment concerns the description and development of *ARtect* prototype, an Augmented Reality (AR) application and online service for mobile devices (smartphones and tablets), intended to facilitate architectural conception, interaction, and visualisation of 3D models and 2D graphics in both interior and exterior spaces. This is an AR CAD approach.

In this thesis, we mostly develop a tool that concerns the evaluation of architectural 3D sketches in a digital $2^{1/2}$ D space (Whyte, 2002) with augmented reality media easy to use by architects, artists, and designers.

We evaluated the application's functionality with experimentations in Paris in France at the beginning of June 2020. First, we used 3D models that we created, such as wooden decks, stairs, bridges, and 3D models downloaded from the 3D Warehouse SketchUp with free licenses such as statues, ionic columns, and urban equipment. Lastly, we used 2D images of trees in 3 different seasons (summer, spring, and autumn) as they appear in the digital library on the bottom of the interface (Fig.95). These elements were satisfactory enough for the first tests to create AR scenes in different emplacements and modify them with these spatial forms on-site.

We verified human-scale proportions compared to augmented objects proportions that we could measure on-site (Fig. 96).

Furthermore, we evaluated the distance of the calibration of the AR grid since it worked from the height of a small bridge when we scanned the water (Fig. 97). The concept of this experiment was to suggest floating decks and nature in the ecosystem of the St Martin canal (Fig. 97, 98). In addition, our experimentations included placing augmented objects on non-stable surfaces, such as the water of the canal, to verify if the ARCore grid still worked (Fig.98).

Lastly, we created an AR scene at the Eiffel Tower with simple spatial elements. We walked through the digital environment, obtaining observations and remarks about the natural and the digital environment (Fig. 95). The different angles of perspective in AR in real-time permitted us to understand the open-air 3D space better. Furthermore, the accuracy and stability of the augmented objects on the scene gave us a 360º field of creation. Finally, we note that at this stage of experimentation, we evaluated only the functionality of the application and not the 3D models presented or the scale of their implementation in the environment. More tests are presented in figures (Fig. 99-104) (also in Annex 3).

We partially evaluated the application; since we did not have the opportunity to test it with architectural students, we did, however, obtain some feedback, which was positive, from four students in visual arts and cinema that witnessed the experiment. In particular, they mentioned that it was interesting to create a virtual scene directly on-site and then walk through it, as they characterised the application as highly immersive. Moreover, the participants mentioned the potential of digital scenography since there is the capacity to place many different objects and interact with them. However, further tests are needed to be able to measure the usability and effectiveness of this instrument.

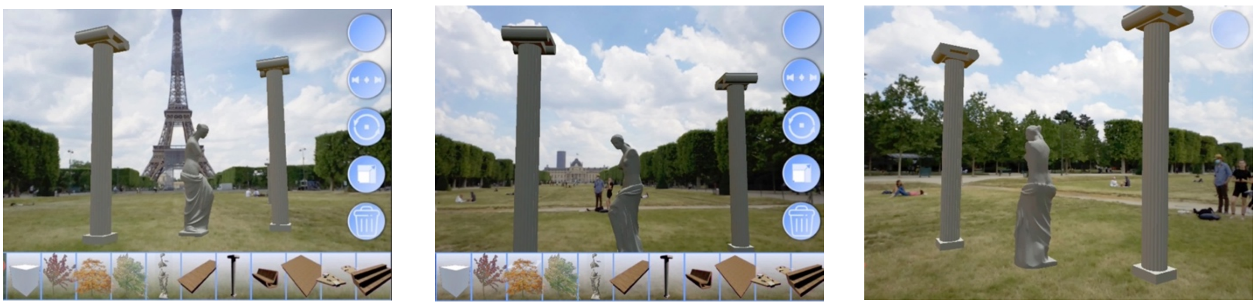

Figure 95. AR Scene, 360º view.

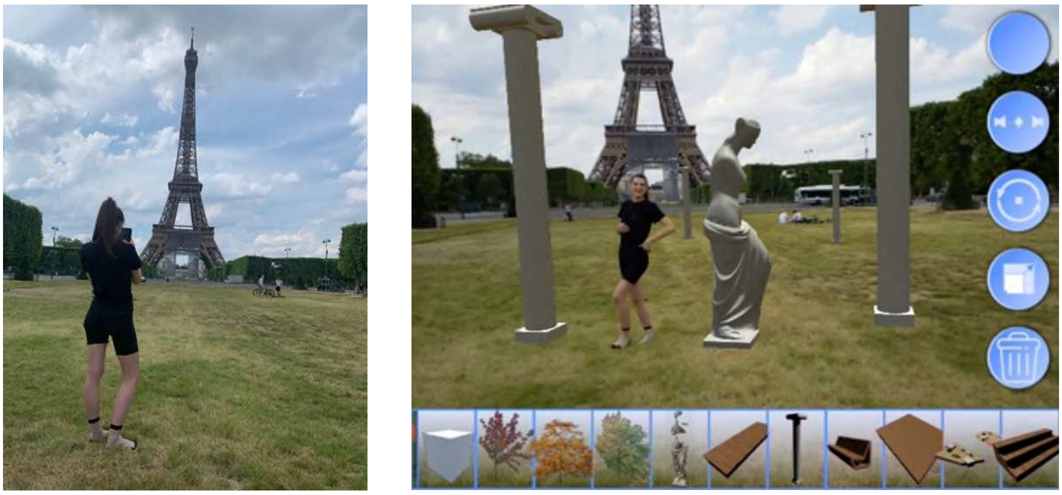

Figure 96. Verifying human scale in AR scene.

The adoption of AR applications by the industry is in progress; also, many academic types of research and tools have been developed around this subject. Our future work is to develop the methodologies that can integrate tools as ARtect in the official educational curriculum of architects and implement a 3D simulation of immersive navigation on a 1:1 scale during academic architectural projects. Besides, the student can use the urban visiting tool to build an augmented reality 'city' route inside the actual city to emphasise important aspects of their design.

Augment with precision virtual objects in real environments, with technological advancements such as cameras, sensors, and GPS present a field of exploration for designers and architects. Moreover, functionalities such as changing material and textures, different lighting simulations, and shaders represent a field for further additions to the application. The application is conceived to fuse later with virtual reality possibilities. In conclusion, the ARCore Depth release permits the 3D objects to be better placed in the AR scene and to improve the 3D navigation inside the digital ecosystem. ARtect prototype considers implementing architectural ideas as a meaningful process to inspire architectural learning by overlaying virtual objects of creation into the real world.

Figure 97. Testing ARtect from height, Canal St Martin, 2020.

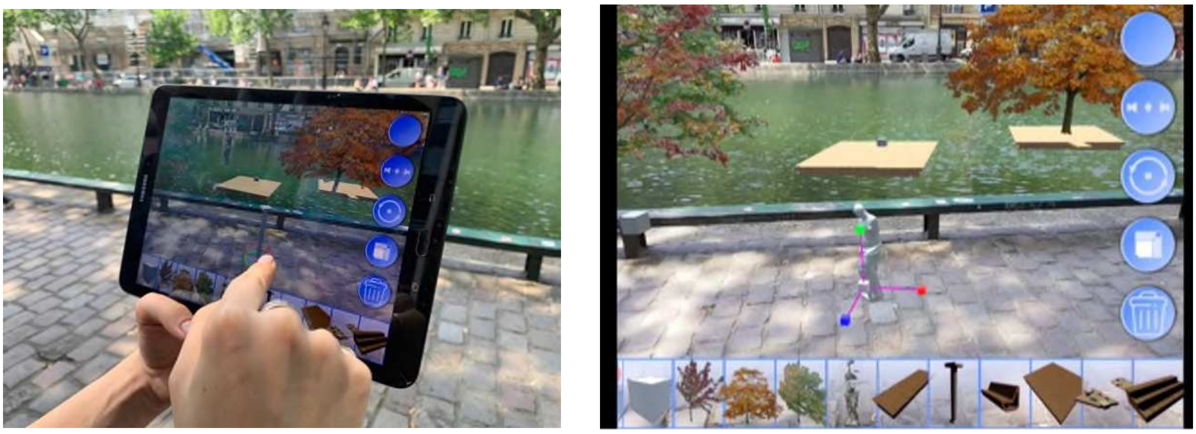

Figure 98. Testing ARtect to unstable surface (water), 2020.

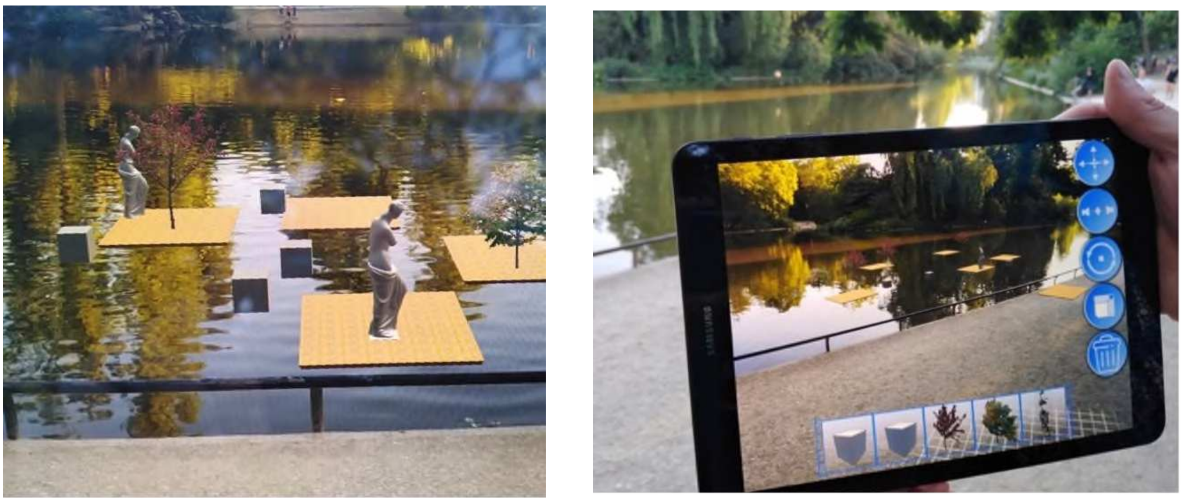

Figure 99. Testing ARtect, Bois de Vincennes, Paris.

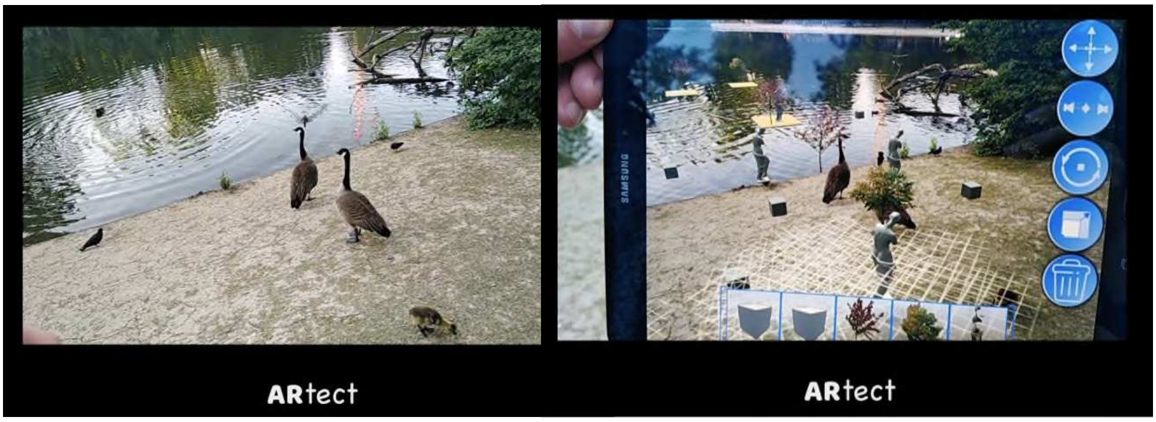

Figure 100. Testing ARtect. AR scene (right) and real scene (left).

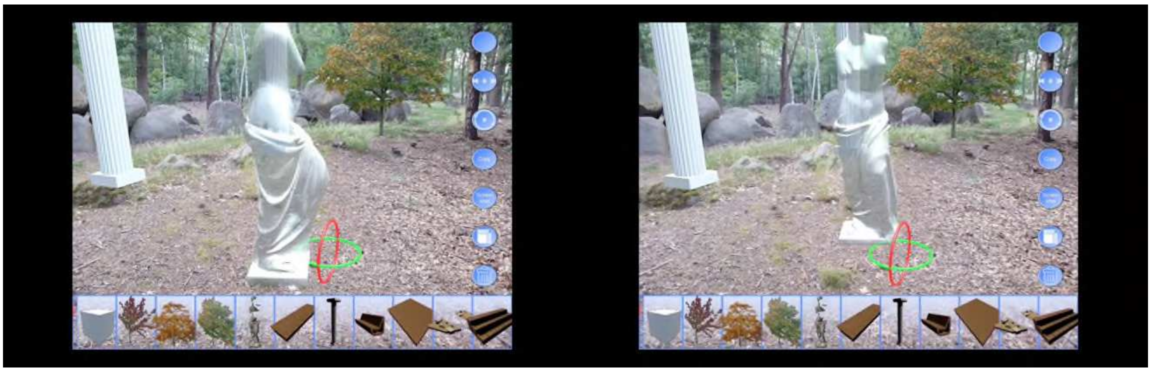

Figure 101. Rotating 3D model with ARtect.

Figure 102. Setting AR Scene with 3D models.

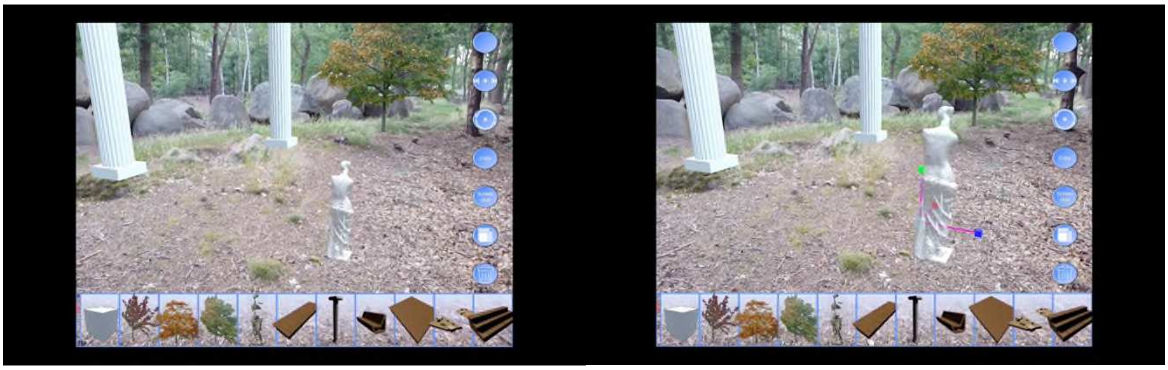

Figure 103. Placing and Scaling 3D model with ARtect.

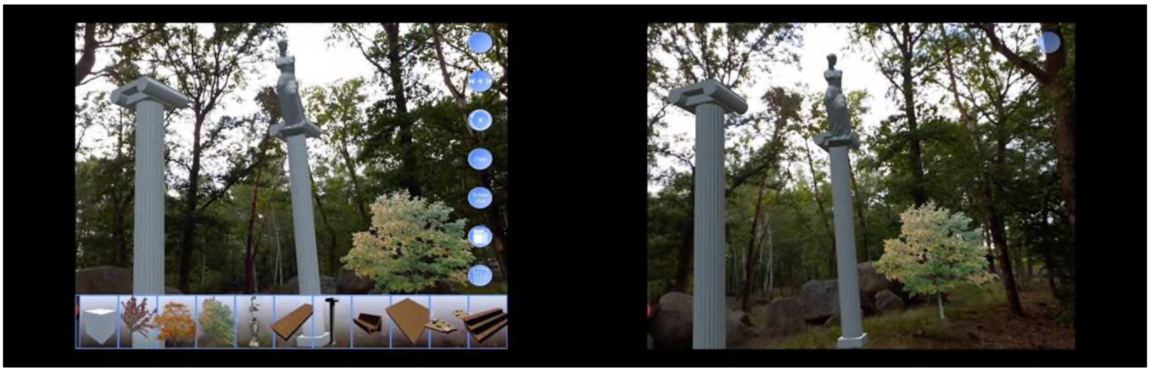

Figure 104. Moving 3D model in z and y axis (left). Hide toolbar (right).

Summary of Part 2

Architects use their hands, and manual gestures are critical during design since they interpret the architect's intentions. Therefore, it becomes a physical and cognitive profession; gestures describe concepts and lines in a flow before transforming the gesture in design and architectural drawing. The learner receives intuitive and pseudo-tactile information to perform design, and this cognitive load processing results to form giving.

We observed the existence of limited immersive practices during learning and teaching architecture. The proportions of immersive levels to grasp during architecture design are still in the process of research.

We developed the five software applications examples as didactic proposals to increase immersion during design. The findings of this research project are expanded in the proposition of architectural education tools and methods that aim to increase students' attention and perception of the surroundings regarding the notion of scale. The applications are based on the learning process of DS in architecture that combines novel interactive technological media with architectural design. Our experimentations focus on:

- Immersion
- First – Person view navigation
- By distance collaboration
- 1:1 scale simulation

The method suggests providing various educational models. These experimentations are presented as samples of intergrading Mixed Reality (VR/AR/Hybrid) platforming in urban planning, design sciences and learning practices about architecture using informatics. This engineering study plans to include art and technology as a cultural tool of design pedagogy for exploration to understand the architectural project. The research focused on the ecosystem of digital media and the overall representational systems for architectural conception.

We deepened into notions of immersion and interaction in relation to the physical environment towards mixed reality teaching architecture methods with the two AR experimentations. Also, using the @postasis platform, we developed methods for remote collaboration between teachers and students in architecture. During the pedagogical process, the elements of immersion and interaction were the keywords for initiating our teaching experiences in semi-immersive and fully immersive virtual environments. The features of interaction and immersion exist in all of our experimentations.

At the same time, the First-Person Perspective view lets the user immerse into a virtual ephemeral identity. Several philosophers consider virtual spaces more like a "spontaneous event than a static and neutral scenery" (Champion, 2019). The conception of architectural space presents a dynamic process of cognitive activity for designers with studies in architecture, urban planning, art and history that can be observed and evaluated in immersive virtual environments.

Some of the aspects to investigate further are relating digital education with cultural, geographical knowledge and historical heritage, as Mixed Reality media reveals the universal approach of architecture as an object of/for design. The media ecosystem of Mixed Reality raises questions about the orientation inside the virtual environment and how the user appropriates the digital space. Self-orientation in an immersive virtual environment can give insights into intuitive design.

Our pedagogical approach describes the conditions where architectural students find the balance between individual and collective design and virtual and real environments. In parallel, we hope to enrich the development of a universal perception of space and environment and raise awareness around the broader concept of Mixed Realities. We insist on the uniqueness of the proposed solutions provided by the students. One of our educational objectives is to offer future architectural students a framework of educational models that include Mixed Reality technologies.

This pedagogy develops critical thinking first and foremost. It does not create experts in one specific field of study, despite the advanced technical knowledge required, using the tool of paper as a desirable way to visualize drawings. The proposed experimentations provide thorough research about education in architecture with digital tools that embrace the technical aspects while keeping a critical eye following the future usage of the advanced application technologies.

Moreover, this approach can cultivate ecological sensibility in architectural education since the students develop an immediate relation between the physical environment (as a whole) and the architectural geometry (as a unit). The placement of geometric forms in the natural and urban environment increases spatial perception and even learning capacity.

In the next part, we provide our analysis concerning these experimentations.

Part 3: ANALYSIS

Chapter 11: Framework of Analysis

In this chapter, we present the comparison of the educational models based on the applications we developed. We note that an educational model comprises a digital application and the relevant theoretical and technical background.

Methods of teaching architecture in virtual immersion: experimentations for the design studio present the concepts of digital realities and the research on the theme of immersive virtual environments (IVEs) applied to architectural design. Our method focused on the development of digital applications. We developed experiments carried out in the architectural design project studio, and we experimented within the framework of a virtual artistic laboratory project. In the end, we experimented with AR applications for the assistance of the architectural design learning process. Finally, we present an analysis of these experimentations. Several prospective elements about architectural perception and design emerge when allowing the implementation of new methods of teaching architecture based on digital realities and immersive environments.

The methodology with the five experimentations we present is empirically based on discovery according to the means and resources at our disposal. It is not a mere hypothesis testing approach, and claiming otherwise would not be explicit.

Our analysis framework is based on Diana's Laudrillard book "Rethinking University Teaching: a conversational framework for the effective use of learning technologies," Second edition.

This chapter attempts to categorize and classify the educational models presented in the previous chapters according to the forms of media we used. We presented the educational models in the chronological order we developed them; however, the classification of these models, if not chronological, can be a notoriously laborious task. The task is demanding since a "deriving teaching strategy from research findings" would not be straightforward (Laudrillard, 2002). The findings based on productive learning activities are the best source for generating teaching strategies and methods for conducting interactive conversations that fully support the learning process (Laudrillard, 2002, p.72). This is why we developed digital applications based on our observations from the contact and the feedback we received from architectural students and teachers.

For the convenience of the reader, we refer to the experimentations based on the applications we developed, in chronological order regarding their completion (Table 4):

Application 1 (A1): Co-learning architecture with hyperlinks in the Parc de la Villette

Application 2 (A2): Behaviour Interactive Interface plugin (BII)

Application 3 (A3): Visit the Unbuilt, Virtually Real

Application 4 (A4): Pixel People—Data Parcours, an augmented reality tour

Application 5 (A5): ARtect, an augmented reality prototype for architectural design

Each educational model is a complete technical and theoretical knowledge package, consisting of one digital application and documentation.

Table 4. Experimental interactive applications for architectural education, 2018–2021.

Application 1 **2018–2019**	**Application 2** **2019**	**Application 3** **2018–2019**	**Application 4** **2019–2020**	**Application 5** **2020**
Co-learning architecture with hyperlinks in the Parc de la Villette (Folie N5)	Behaviour Interactive Interface plugin (BII)	Visit the Unbuilt, Virtually Real	Pixel People –Data Parcours, an augmented reality tour	ARtect, an augmented reality prototype for architectural design

We classify the five educational models into two categories according to the media used for their development. The first category is one of the 3D online multi-user platform designed to host students and teachers digitally while functioning in real-time (as the virtual laboratory, @postasis Framework). The second category includes the educational models of augmented reality (AR) that are permitted to describe a teaching method in situ that brings the background of the physical environment inside the architectural design space.

We note here that we cannot generalize the findings of our research, only the methodes that we followed.

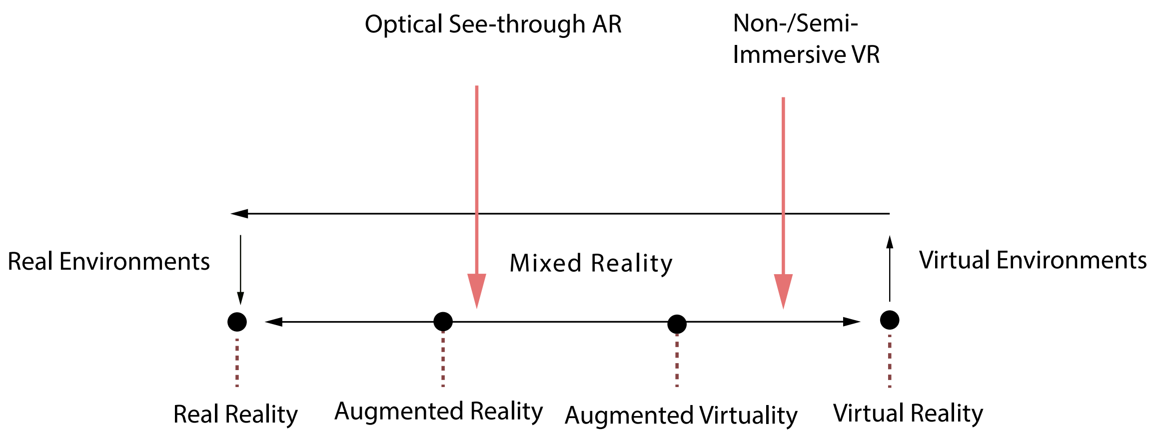

Figure 105. Immersion in relation to cognitive presence.

The red arrows signify the two categories of our methods and their placement in the Mixed Reality Continuum, based on Milgram's diagram (1994) (Fig. 105).

In between AR and VR which support fully immersive experiences, we identified the semi-immersive VR environments.

We place the suggested experimentations as applications inside the Milgram's Mixed Reality continuum (1994). Furthermore, we also added the 'reality offline' and 'reality online' modes in Milgram's continuum diagram of Mixed Reality, concerning the possible connection to the internet while performing a design activity to assess the relationship of MR and cyberspace (Fig. 106). The cognitive limit is perceived here as the limit before operating an activity with the computer, the limit between human and computer, and the screen's physical limit (Fig. 106).

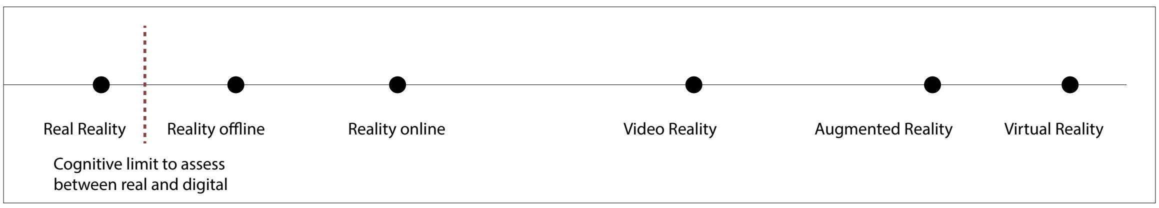

Figure 106. Reality-Virtuality Continuum modified, assessing the cognitive limit. From real to digital environment.

The educational models described in Part 2 provided insights about:

(1) What it means for the tutor and what it takes to prepare such courses based on theoretical and technical knowledge. The knowledge obtained lies in digital reconstruction with 3D models, dynamic elements (such as water and wind simulations), and 2D trees (sprites). Also, knowledge about informatics for beginners, such as the script for hyperlinks, is provided.
(2) The learner's participation as the creator of digital content with 3D objects, given the architectural design framework. Application development provides technical knowledge about informatics, notions like virtual buttons, colliders, shaders, triggers and tags. The learner can also use prefabricated 3D models as the purpose of some courses is not the modelling but enabling real-time navigation, spatial awareness and creation of interactions with other users or virtual entities.
(3) The digital recreation of complex urban environments. Certain qualities of the physical environment become simulated real-world elements and are examined via interfaces.
(4) Attending an event or a course by distance, including conferences and exhibitions held both in virtual and digital spaces. We also discuss the dependence on specific locations during architectural learning.
(5) The experimentations that refer to the learner's digital experience as a creator and participant of augmented reality experiences. This part means that the learning process, when focused on designing interactions within a virtual environment, can be beneficial for architectural design. We provide a framework for understanding the transitions from real to virtual environment coherence.

11.1. Categories of Methods

The first method of experimentations, which was based on the 3D online multiuser virtual laboratory platform, led to the development of Application 1, Application 2 and Application 3.

This method was developed with the participation of the Paris 8 University (France) scientific team, as mentioned in Chapter 7, the group[28] of Athens School of Fine Arts (Greece), within the framework of the European project for artistic collaboration by distance.

For our experimentations, inside the framework of the joined supervision thesis, architectural students from the National Technical University of Athens and PhD students from the laboratory MAP-MAACC (Modélisations pour l'Assistance à l'Activité cognitive de la Conception) participated. Moreover, several artists, teachers and researchers during the Multiplier events held in the different EU countries participated in our experimentations.

The second method of experimentations includes the applications of augmented reality (AR) developed within the framework of this thesis in collaboration with Emergent Art Center[29] (Eindhoven, Netherlands). Application 4 and Application 5 are digital AR experimentations. These applications were tested by the public, who participated in the experiences and a few architectural students and artists. The generic target group combined different ages, cultural and scientific backgrounds of the participants.

Application 4 is situated-based, meaning that it functions only for the geographical locations that it was created about (e.g., Eindhoven City). On the contrary, Application 5 provides less orchestral experience, building a dynamic system with the computer and the geographical coordinates concerning the user's position. The Application's 5 system liberates the user in terms of accessing the immersive experience in any physical environment (indoors and outdoors).

The fundamental difference between these two categories of Mixed Media (Webinar platform and AR) is that the first discusses virtual environments that can be considered non-immersive or semi-immersive. The first category approach focuses on distance collaboration inside the 3D multiuser virtual environment rather than increasing immersion. The second category of AR included the applications that can be considered fully immersive.

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[28] Manthos Santorineos (Coordinator of @postasis project), Voula Zoi (Coordinator of @postasis project)

[29] The Pixel People-Eindhoven Data Parcours (Application 4) project is an initiative of MAD Emergent Art Center and Smart House in Eindhoven. Pixel People was created with the cooperation of Richard Pasmans (Developer), Richard van Roy (Developer), Maria Velaora (Engineer of Studies) and Rob Verhaar (Coordinator). The Pixel People was made possible by the financial support of Vogin and the GO Fund foundation.

Therefore, Applications 4 and 5, suggested for the educational models 4 and 5 accordingly, are immersive because there are directly developed in AR by employing the *Location AR* script we developed (Chapter 9). The other three experimentations (Applications 1–3) for the related educational models are semi-immersive since the user develops activities and interactions in the virtual space through a virtual-person controller, a virtual actor and an interface for parametrizing conditions.

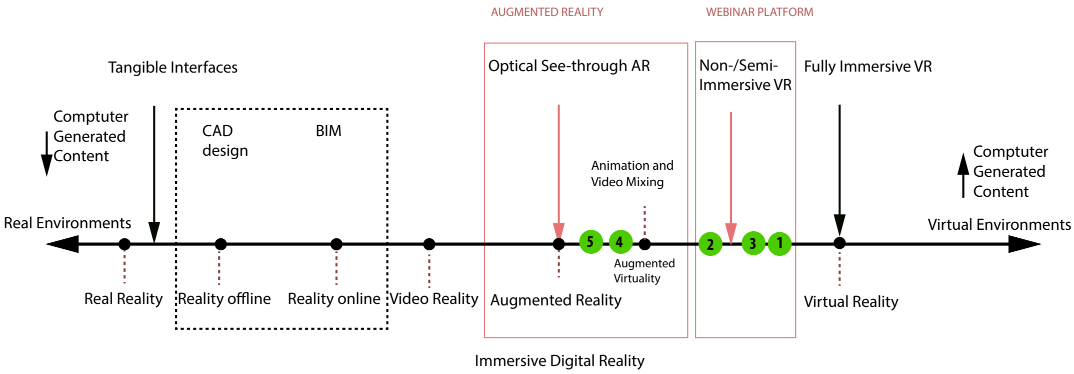


Figure 107. Placing the categories of the experimentations based on Mixed Reality Milgram's (1994) modified diagram.

The critical element to understanding learning through immersion is the notion of 'presence' inside the virtual environment. To create a fully immersive learning experience, the three stages[30] of immersion are fundamental: engagement, engrossment and total immersion (Brown and Crains, 2004). Augmented Reality applications are fully immersive since as learning method merges two different "materials" and utilises a mechanism to combine the virtual project and the real environment, ensuring that the user "receives a consistent set of sensory inputs" (Zlatanova, 2002). We place our experimentations (Applications 1-5) in the suggested Mixed Reality continuum (Fig. 107).

From Milgram's diagram, we observe that highly immersive environments are considered the environments of reality, augmented reality and virtual reality. In between this reality transition, from real to virtual and vice versa, is video-reality, which is considered a lower immersive experience. Low immersive environments such as webpages, social media,

[30] Emily Brown and Paul Cairns. 2004. A grounded investigation of game immersion. Extended Abstracts on Human Factors in Computing Systems. Association for Computing Machinery, New York, USA, 1297–1300.

YouTube videos, several gaming applications (serious games) and cinema, do not engage enough the learner during the learning process in performing new activities. Low immersive environments limit productivity and digital creation since they develop passive forms of the learner's participation as an observer, providing limited space for communication and expression. The learner can apply these media forms for description about a topic, technical tutorial knowledge and other information and communications, based on narration and graphical user interfaces (GUI).

This observation about the semi-immersive environments, between highly immersive and low or non-immersive virtual environments, led us to suggest a diagram based on the Mixed Reality Milgram's diagram. Different media forms of Mixed Reality provide a variety of virtual environments, from non-immersive to immersive. The nature of the visual interface of the applications, between the user and the computer, is key to understanding the different levels of immersion (low, semi, high). We reconsider the Mixed Reality continuum concerning the levels of immersion. Levels of immersion in virtual environments are related to a coordinate system of the user (internal coordinate) according to a reference point inside the real and the virtual world. We suggest 'bending' the Milgram's continuum concerning the immersive experience they build (Fig. 108) and placing video reality as the lowest immersive digital environment.

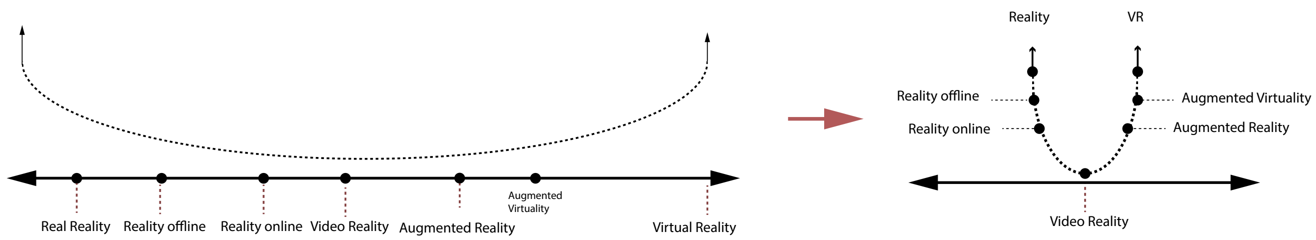


Figure 108. Bending the Reality-Virtuality continuum.

According to the diagram, the sense of presence alters according to semi-immersive and fully immersive virtual environment applications.

The user's coordinate position is useful to be investigated with the coordinate system of the physical environment, also this of the architectural object inside the virtual environment. The conception space is an internal cognitive place, while the computer and the physical environment provide external coordinate reference systems. The displacement between the internal point of reference (designer) towards the external points for design (Table 5) often creates several cognitive biases that are transferred later in the architectural design.

The object of the architectural work is a work on a scale that derives from internal coordinating systems. The detachment of the architectural student from the actual object of architecture in the site of implementation created difficulties in learning design and perceiving space.

We provide a schematic representation that groups the virtual environments into two categories: low-/semi-immersive and highly immersive environments. This approach places the learner's position (presence) in the center of the experience (continuum) (Fig. 110) in order to identify the nature of a certain mixed media environment. The learner's presence is connected to the learner's cognitive space to perceive and design spatial relationships.

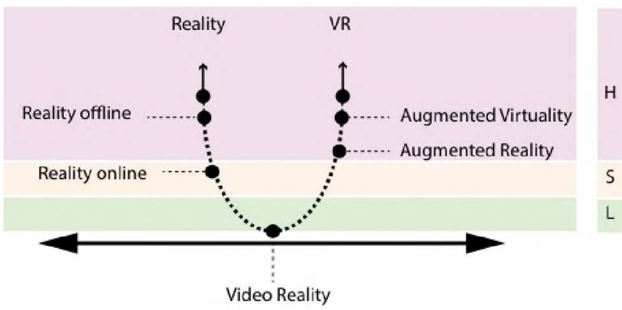


Figure 109. High (H), Semi(S) and Low (L) Levels of immersion to the curved Virtuality-Reality continuum.

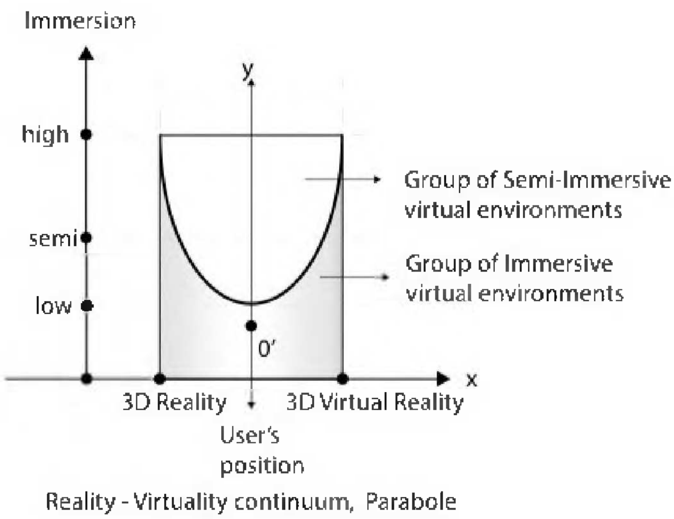


Figure 110. Group of immersive and group of semi-immersive IVEs.

Table 5. Classification of methods for integrating digital technologies in architectural education.

	Application 1	Application 2	Application 3	Application 4	Application 5
Category	3D online multiuser real time platform	3D online multiuser real time platform	3D online multiuser real time platform	See-through Augmented Reality	See-through Augmented Reality
Nature of interaction	Hyperlinks and web pages	Interface (setting values)	Interface (setting values)	Smart city, data, Internet of Things	Virtual geometries and 2D/3D elements
Nature of visual interface between computer and user	Virtual-world coordinate system	Virtual-world coordinate system	Virtual-world coordinate system	Real-world coordinate system	Real-world coordinate system
	Internal coordinate space	Internal coordinate space	Internal coordinate space	Computer System	Computer System
Media of interaction	Mouse and large-screen display	touch screen/mouse	touch screen/mouse	touch screen	touch screen
Immersive	Semi	Semi	Semi	Fully	Fully
Display systems	Monitor based, Window-on-the-world	Monitor based, Window-on-the-world	Monitor based—Portable Device	Video see-through system	Video see-through system

As there are many different subjective ways of conceptualizing and addressing various design topics we want to teach, especially in the design studio process, we placed the focus on the shift from "what a teacher should do" to how the teacher sets up the interaction and reflects the fact (Laudrillard, 2002, p.71) and the design issue. The acknowledgement of the necessary resumption and connection between the teacher, the learner and the content of a design issue is "more realistic than the cause-effect models" (Laudrillard, 2002, p.71) of the PBL (problem-based learning) model suggested by learning theories like cognitivism and instructional design. IVEs are efficient environments for studying phenomena through simulation.

11.1.1. Students and Teachers' Role

We are far from claiming that we have solutions for all the students' needs and difficulties. Despite the thorough research, the solution may not necessarily be found on the new ways to communicate the several design difficulties. The media forms of Mixed Reality may facilitate one difficulty but can also create others that we cannot anticipate or predict. The object of architecture is conceived simultaneously on different scales, and it is rather an object of thought than an object of matter. The finality of the architectural object is to be perceived on a 1:1 scale (human scale). Therefore, our teaching strategy places the dialogue about the learner's position in the centre of our method since it reveals learners' conceptions, internal operations and determine the focus of the process (conversational framework).

Henceforth, the teachers of architecture methods focus on the learner's experience about the object of learning and the background that the learner carries. This is why we considered it important at the beginning of our methodology to interrogate students about new technologies and their opinions about MR media to import their feedback into the academic dialogue.

Teachers of universities have to take into consideration the background of the upcoming generations that are growing into the Internet, the online connection, the constant data and content flow.

We identified two ways of possible integration of new media in the academic curriculum of the design studio. One way that teachers can integrate IVEs into architectural education is to "build a relevance structure" to a certain topic (Laudrillard, 2002, p. 69). This approach can lead towards possible gamification of architectural space with the participation to webinar courses of students from all over the world, including the development of advanced space syntax strategies. The second way refers to the "architecture of variation" (Laudrillard, 2002, p. 69) to enable learners the flexibility into changing from one conception to another, especially during the design process.

Based on Laudrillard's principled approach for generating teaching strategy and method, we present the organization of criteria about the students and teacher role when adapting each of these examples.

We elaborate on each aspect of the process to demonstrate what roles and tasks students and teachers should play in the interaction (Laudrillard, 2002, p.72) (Table 6).

Table 6. Students and teachers' role in the learning process with digital media.

Educational Applications	Students and teacher roles in the learning process		
	Aspects of the Learning process	**Student's role**	**Teacher's role**
A1	Apprehending structure, reconstructing architectural components of the environment	Look for structure, virtual environment hierarchy, discern topic goal, create hyperlinks based on topics	Explain phenomena of design (variations of architecture), clarify the structure, ask about internal relations of multiuser aspects
A2	Acting on descriptions, setting conditions	Derive implications, solve problems based on possible virtual inhabitation, tests, produces descriptions, a new scenario	Elicit descriptions, compare tests, highlight inconsistencies, test different environments
A3	Using the feedback of applied conditions	Link teacher's redescriptions to the relation between design action and goal, to produce new design action on a description	Provide redescription of visiting the unbuilt, elicit new description, support linking process
A4	Interpreting forms of media and representations	Model systems of interaction in terms of forms of representation, digital model interactions with physical environments	Set mapping tasks between forms of representations and events/systems Relate form of representation to the student's view
A5	Reflecting on goal-action feedback cycle based on volumetric dispositions	Engage with goals, relate to actions and feedback	Prompt reflection, support reflection on goal action-feedback cycle

"The point of a good classification system is that it should be powerful enough to embrace the ideal as well as a recognizable reality, and thereby make the shortcomings of our realities apparent" (Laudrillard, 2002, p. 83).

Another aspect of implementing IVEs in architectural education is to bridge the gap between manual design, CAD, VRAD (VR Aided Design, Chapter 3) and AR CAD.

Application 5 (ARtect) is inspired by CAD design logic. Mixing the traditional digital tools that architects use with virtual interactive 3D environments can create new experimentations for the learning process of architecture (Fig. 111).

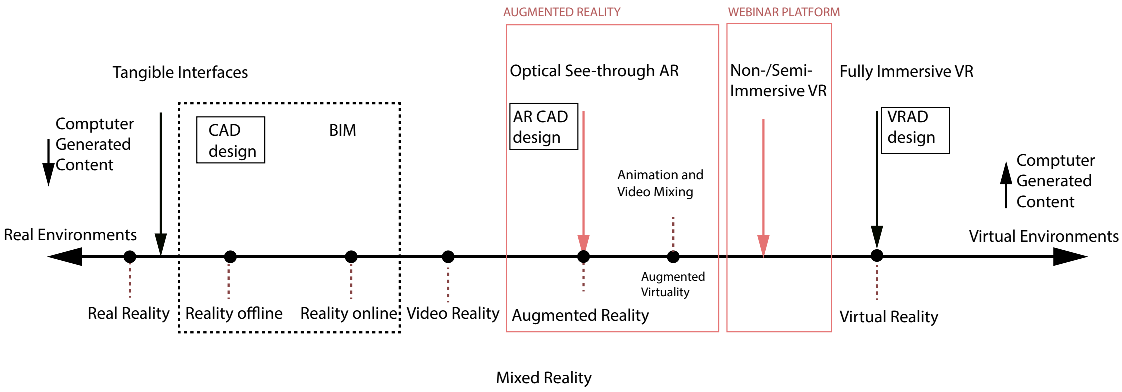


Figure 111. CAD, VRAD and AR CAD in the modified Mixed Reality continuum.
(The red arrows indicate the placement of our experimentations)

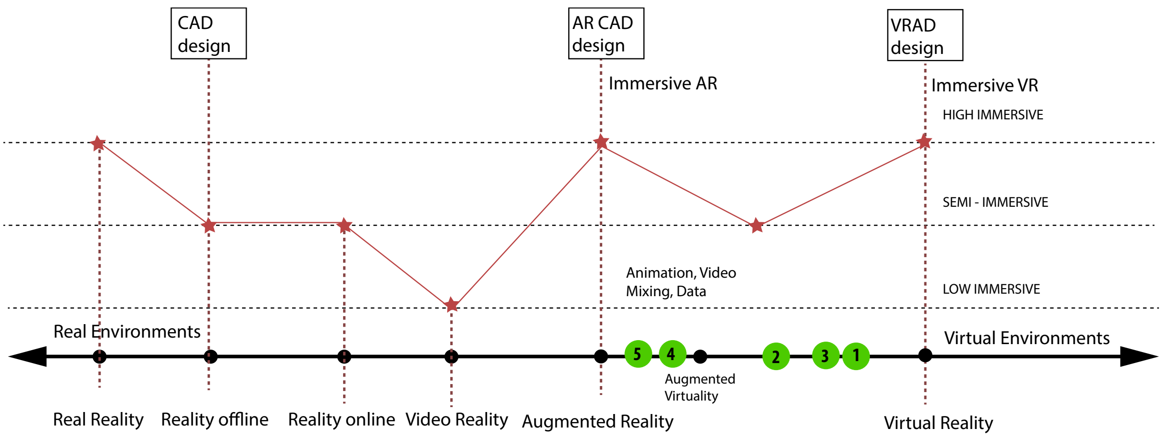


Figure 112. Placing our experiments in the Mixed Reality continuum in relation to levels of immersion.

Video reality is seen as a low immersive experience. Reality offline and online can present semi-immersive environments. Finally, AR and VR environments are seen as fully immersive (Fig.112).

11.1.2. Analysis of educational models

This chapter analyses the empiric approach we followed, which combines architectural knowledge design skills of theoretical and practical background with software development.

We attempt an overall analysis of the experimentations under the following common criteria. The criteria we evaluate our investigations are based on the educational outputs of each experimentation, on learning criteria such as individual learning, in groups, by distance and on learning activities related to the fundamentals of architectural design.

Finally, we apply the fundamentals of architectural design (Chapter 4) to evaluate our experimentations and what benefits can bring to design (Table 13, see: Chapter 11.3).

- We examine immersion as a shared experience for learning that engages the learner in passive, active activities and participation through observation. Our method discusses basic notions of design. The technical knowledge requires 3D modelling skills and targets students who want to become familiar with computers. The technical knowledge obtained for the learner is coding skills for beginners and additional assets concerning situated learning (navigation, site, location, GPS). Our method aims in cultivating to the student the awareness of self-evaluation in design. Also, our method values flexibility during conception, collaboration and the expression of the learner. The technical knowledge derived from Mixed realities (triggers, virtual objects, online interactions) can assist architectural education and graphics.

We investigated architectural issues (e.g., geometries, structure, volume, lighting) in virtual environments, and we presented digital simulations for the design studio. We focused on learning architectural design through navigation and interaction within 3D interactive environments (virtual and physical). Our educational models are designed to evaluate flexibility and adaptability in architectural representation during the learning process of creation (adaptive and reflective process). We discussed the virtual presence and the first-person perspective, and the possibility of educational integration of such models.

At the end of this analysis, we suggest a classification ranking of the experimentations we developed based on an overall evaluation (levels of immersion and architectural issues).

11.1.3. Teaching barriers

The level of immersion into design experimentation has a fundamental role in the experience and the results. The teacher has to adopt the method concerning the exercise in question. For example, if the design project refers to a specific site of implementation, a tour in the urban environment, or discusses the possible interactions with specific locations and points of interest. The barriers of accessing the mixed reality applications for architectural education are various.

The teacher's main task in architecture shifts from the descriptive and narrative feedback about the architectural object to the "mise en scène" of installations or interactive virtual and computational environments systems. The teacher's challenge is to match the learner's preferences about the topic. Student engagement is fundamental for evaluating interactive media since the investment of time is mandatory from both sides. The lack of time investment due to the unwillingness to invest or the unavailability of time during the academic curriculum can be a basic barrier for these practices to receive further and extended feedback through experimentations with students.

The barrier about the students' engagement is a challenge for the teacher to maintain control of the learning process and provide intuitive and easy to learn methods for the architectural synthesis.

According to Brown and Cairns (2004), a low immersive VE becomes semi-immersive when learners accept their surrounding environment and successfully ignore external distractions. Ignoring distractions is the stage of immersion engrossment. To eliminate distractions during the cognitive process of design, the teacher's challenge is to surpass the barrier concerning the "depth of the world." According to Brown and Cairns, the depth of the world is a barrier since the virtual environments (usually 2D representations) must be visually believable, provide meaningful activities, and orient the learner to follow a believable narrative in a perceived as three-dimensional space. We explained the difficulties of placing 3D models in x,y, z-axis (depth and height) in a 2D screen in Chapter 10.

Furthermore, the teacher should raise awareness about the extensive use of IVEs.

In addition, navigation and free movement inside a VE permits the learner to observe the design in motion, as spatial coherence and sequel. This cinematic navigation inside the VE creates a sense of visiting and habiting the virtual space. This effect has an important role when visiting a virtual environment and navigating in a First-person or Third-person view.

The controller's different optical viewpoints assist the engrossment of immersion in the IVE according to the internal coordinate system of the 3D architectural model. The interaction and the motion of the controller (first or third person) merge the internal cognitive space of the student with the coordinates of the virtual 3D environment. This merge in coordinate systems as a reference point amplifies the sense of presence enhanced in immersive 3D virtual environments.

Finally, the teacher's purpose of augmenting levels of immersion is to engage students' participation so that the latter achieves a psychological sense of being present in the VE. The 'flow' during the digital performance of the application plays an important role in the learner's effort to complete the activity required.

The barriers for the IVEs are also psychological since the increasing attachment must not be turned into an addiction. Moreover, the embodiment of the designer as a virtual character or entity can lead to meaningful architectural design ideas, but the barrier here is technological. The last barrier with the use of IVEs is that teachers can raise awareness about the development of designing skills and spatial perception. Still also, the learner should be protected by a possible loss of awareness about the real world (presence) and loss of time awareness (flow).

11.2. Educational Models Analysis

Educational Model 1

The experience was made possible with graphical computing and large projector systems.

The first educational model (Folie N5: Co-learning architecture with hyperlinks) used the online platform @postasis, developed with the game engine software (Unity 3D). The student had to create a profile connected to a standard 3D room from where the learner had access to create a virtual scene or a virtual avatar. The method applied in this educational model is a game-based logic approach used in fine arts, design and other creative industries.

The practice demanded the employment of little design skills and informatics coding knowledge for beginners. To create the virtual interactive environment, the student must finally follow a specific hierarchy to connect to the platform. The difficulty in accessing the platform and operating in it decreases the architectural student engagement and motivation. Once the student becomes familiar with the platform, the learner can start the experimentation.

Platforms require a lot of memory storage space, powerful graphic cards, compatibility and easy access to the Internet. These can be seen as additional obstacles that add cognitive loads to the students instead of facilitating the design process.

The sense of presence in Educational Model 1—Engrossment of immersion

In the educational model 1 specifically, the goal was to combine the actual place, the fact that the participant was already in the Parc de la Villette attending the Third Multiplier event (18–19/04/2019) inside the building of the Folie No.5 while navigating the Parc de la Villette as if in a video game.

The interactions in Application 1 permitted in the virtual space concerned interaction with hyperlinks and online web pages, navigating on a virtual exhibition concerning texts and drawings of the Park (ground floor), and participating in real-time virtually in the conference on the second floor. The conference related to the event took place simultaneously in the physical and virtual space, giving the possibility to the public to participate by distance and accessing the speakers' PowerPoint presentations. This feature does not exist in the final educational material provided on the platform's website since it was related to the actual event at that time.

With the first Application (Model 1), we attempted to initiate the learner to the concept "from real to virtual" and vice versa. The idea that the learner is simultaneously present in the same virtual and physical space can be applied in several spaces, such as museums, libraries, public spaces, houses. The organization and the coordination of the @postasis platform chose the place of the Folie firstly as the place to host the multiplier event, months before the event, and then we adjusted the application accordingly. If another location was chosen, then the virtual environment, also the narration inside it, would be different.

Therefore, this approach emphasizes the existing physical space in the narration created inside the virtual space to guide the learner. We characterize this model as a model of design that promotes descriptions, imaginative immersion, and emotional involvement. Therefore, Application 1 presents a narrative learning process inside the 3D interactive virtual environment.

As presented in educational Model 1, the digital Parc de la Villette demonstration shows that 3D space as the geometrical disposition of models is insufficient to organize an interactive virtual experience (pervasive mobile game). The interaction between user and virtual space remained in the primitive stage of clicking (mouse click), and the links transferred the user to relevant web pages. No further data were involved (quests, questions, ray cast, etc.) during the participant's navigation.

More anthropological features must be considered in designing such informatics solutions to engage the student in architecture in learning specific aspects of design. This experiment can benefit the learner in analyzing the existing space (points of interest, floors, access to natural elements) and reconstructing it digitally. The digital reconstruction does not have to be in detail, but it has to present the main characteristics. This educational model is not a tool of spatial synthesis and design. However, the educational approach includes aspects of real-life design within the framework of the semi-immersive experience. Indeed, such an approach can take place in malls, streak museums, schools, countryside. Outdoors virtual environments are a new framework of architectural learning combined with mobile devices and online access.

Navigation

Interaction and discovery flow

The flow of navigation and interaction is what adds pleasure to the experience of the learner. The flow translated in architectural design is when the design contributes to the happiness experienced by the potential future inhabitants and visitors. The architectural example of the physical Parc de la Villette combines natural elements with contemporary structures. The surrounding buildings (Cité de Sciences et de l'Industrie, Philharmonie de Paris, Grande Halle) shape a scenery of various architectural styles. Thus, the real Park has a unifying role, maintaining its homogeneity playfully and surprisingly. The Folies are a network of structures participating in the transmedia narration about the space.

The interactions of such an educational approach are quite constrained. The digital environment has to motivate the learner and provide learning effects, and educational Model 1 is evaluated on motivational and pedagogical results.

Lastly, the relevant architectural knowledge is hard to share between experts in architecture and game developers (Mader, 2016) and vice versa.

Our method aimed to propose a strategy for architectural environments (geometrical organizations, navigation, interaction) that guides the learner to apprehend space with multiuser and real-time tools to deal better with design challenges. The architectural student has to maintain the bigger picture deriving from the spatial analysis since the primary purpose of the design exercise is to teach the architectural student how to design digital interactions in the 3D space. The learner's practice in shaping a "natural" like environment and placing the significant (symbolic) elements such as buildings, trees, bridges also has to put the ingredients in a distance that the digital participant quickly explores. Digital interactions by inputs like a mouse click, keyboards, voice recognition, and other digital feedback can participate during the digital reconstruction of the Park in the future.

The educational model combines the exploration, discovery and analysis of a natural world environment with the technical requirements of 3D software. 3D software permits learners to design interactions, providing visual representations significant for the architectural design process. The learners start to observe the existing virtual and artificial environment and attempt a narration by navigating a relevant 3D simulated through hyperlinks.

Architectural design is a highly contextual work that balance attributes from the outdoors existing environment. A playful approach in architectural education does not lack meaning and creativity in terms of spatial qualities. Before any attempt in modelling creation, the student learns to observe and reconstruct a simulated environment digitally. Other assets and plug-ins can be added to the toolbox of architects, such as virtual buttons, movement of the actors and bird's eye new perspective.

The quality of learning through digital and physical presence in a certain environment remains under research.

Based on the @postasis framework of the relevant EU project, this approach investigates learners' attitudes further toward virtual reality learning environments (Huang et al., 2009). Neuroscientists claim that simulation of natural events and social interactions provide "ecological validity" (Bohil et al., 2011) since these virtual environments are not limited to only the necessary features for an architectural design experiment. A semi-immersive digital environment can be informational, explanatory, analytic, and insightful since it provides rich contextual representations similar to the real-world setting. In educational model 1, the semi-immersive virtual environment (screen projection), the displaying virtual interaction and information provide sensory input about the physical environment. However, the body's movement and the virtual environment's sensory flow (Bohil et al., 2011) are not coupled as the interaction occurs through the mouse click. Thus, it remains a semi-immersive system that provides feedback about representations and simulations of surfaces and texture, also a terrain where the user can interact with virtual objects.

Educational Model 2

The learner can control virtual actors or interactive activities within the experience, but the virtual environment is not directly interacting with the learner

The second educational model (Behaviour Interactive Interface) is a plug-in software for the @postasis platform. As part of the scientific Team of Paris 8, we developed the Behaviour Interactive Interface (BII), providing the multiuser platform with the possibility of virtual population and inhabitation tools. The design of such an approach combines virtual actors (agents) with the virtual environment. The BII plug-in was presented in the Second Multiplier Event of @postasis in Eindhoven and later in the Third Multiplier Event in Paris in 2019.

The category of this digital demonstration belongs to a standalone or "sandbox" (bac-a-sable) type of application. It remained in the pilot version. We analyzed the theoretical and technical approach of this demonstration plug-in. One of the primary purposes of this software was to provide a dynamic system of generating digital population inside 3D virtual environments, creating a hierarchical genealogy between virtual objects (3D objects, 2D sprites and empty game objects). The populated virtual environments are widely used in computer games as virtual actors, agents or avatars and often demands knowledge of Artificial Intelligence (AI).

We focused on exploring "randomness" and random movement inside the virtual environment. The purpose was to create a dynamic display system for virtual actors to distribute tasks and attributes to the virtual entities.

We needed to create a "limited" self-regulated system where the different students collaborate and auto-evaluate their proposals. Given the surroundings of an abstract virtual space, we tested several features by repetition of actors' movements. We attributed to virtual actors’ random movement to observe the passive intentionality that emerges from the dynamic digital system due to randomness and unpredictability.

Finally, the aim was to raise awareness about 3D space and the digital occupation of space by virtual agents. Human behaviour tends to choose walkways dependent on their environment and other moving subjects. The subjects (virtual and physical actors) tend to change the direction of movement, speed or scale to avoid collision with another moving subject or static object (Rymill & Dodgson, 2005). The element of collision avoidance between humans can be transferred into the digital environment as a primitive form of virtual actors' interactive behaviour.

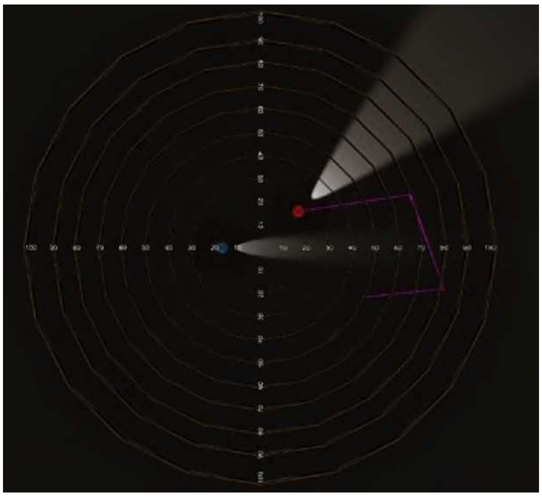


Figure 113. Metrics and Random movement in the virtual environment, BII.

Setting the metric system in a VE from a 0 (0.0) point demonstrates a Cartesian logic about positioning the FPC (first-person controller) in relation to the pivot point of the 3D model. This metric system permitted us to study the behaviour in relation to the random movement of virtual actors in the VE (Fig. 113).

However, in the limits of this research, aspects of human behaviours such as emotions, attention points, memory, and language processing are not examined. This could lead to immensely complex approaches to architectural design. Our findings can be considered simplified or reductive if we compare this application with populations in video games.

The interface is designed to support three types of virtual characters as avatars and NPCs (empty objects). The virtual actors are characterized as generators, amplifiers or destroyers according to the function assigned to them. We investigate processes such as spawn, destroy, follow to create a generative system of behavioural features that can be self-generated and self-organized.

Genealogy and Informatics Knowledge

There are functions related to movement, amplification and generations of a virtual actor. Operations associated with looking towards (LookActor/LookAwayActor) following (FollowActor), copying direction (CopyDirection), increasing or decreasing speed, moving up and down (Ascend/Descend) were tested in the virtual environment, which are functions related to movement.

The character of amplifiers' virtual actors operates with functions related to scale (Increase/Decrease) and speed (Increase/Decrease). Lastly, the tasks associated with the generation of virtual actors are SpawnActor and DestroyActor.

The functions mentioned above operate under conditions of proximity and collision between virtual entities and time count. These conditions of distance, time and collision set the parameters for different tests of virtual inhabitation.

Navigation

The *movement* defines the virtual actor's relationships and interactions with other virtual entities (passive or active). A passive actor (static feature) can become responsive if activated or triggered under conditions. The movement of the virtual actor sets dynamic navigation. The virtual actor can follow other actors into the 3D environment, and this movement can be directional, or target based. Also, the movement can be constant forward or random.

The main functionalities of the movement are based on avoiding collision with the environment or enabling collision with objects or elements of the virtual environment. A target-based mission is assigned to a virtual actor through the "patrol" function of the movement, which means that the actor performs on a "tagged" of a "labelled" group of actors. The direction movement can also be set as a path by double-clicking in the 3D space (patrol/waypoint/map).

BII allowed architectural students to add a set of actions to virtual agents during the design process of modelling architectural space. These actions include that the student can easily modify the position of moving virtual actors and control the generation and destruction of these virtual entities. It gives the possibility to create new elements and destroy others. The plug-in also facilitates students to trigger animations, creating an eventful 3D environment.

Finally, BII permits changing the state of the 3D objects from static to dynamic, as this software is designed for self-regulation and auto-evaluation of architectural students and artists. Under the distance (proximity and collision) and time count conditions, the students inhabit a virtual environment from different locations, setting alternative condition values.

For our experiments, we created a Cartesian point of reference as a metric system with concentric circles to define and understand the interactions of virtual actors, also to measure time and distance in the VE.

Our experiment with random movement and metrics led us to conclude that complicated or complex virtual environments (with obstacles) influence the evolution of the digital population dynamics in space and time. For example, we created a Voronoi surface procedurally with subtracted islands, simulating the streets of an imaginary urban environment. The observed behaviour of virtual actors about avoiding obstacles was similar to the human.

This educational model demonstrates human intention and determination in terms of spatial structure and organization. In contrast, in terms of random movement, the machines leave the possibility of new design patterns.

Aside from different attribution of values to conditions, we experimented with different 3D space set-ups. For example, we created a digital room with obstacles and walls to observe the development.

The research about the plug-in can continue in many different aspects that concern architectural design and artistic creation. It facilitates collaborative creation in 3D space and virtual inhabitation in a game-based logic of virtual actors.

It is crucial to mention for the reader that the educational models and demonstrations presented in the thesis are seen as a sequel of an educational approach. They do not merely present independent examples. We introduced the webinar course about the Folie N5 of Parc de la Villette in the first model. The student has been initiated in reconstructing an existing environment digitally and creating simple interactions through navigation in the digital environment. The BII plug-in is a toolbox for virtual population interaction and behaviour that can be further studied in several abstract and geometrical virtual environments.

Educational model 3

Visit the Unbuilt

The learner controls some characters or activities within the experience, but the virtual environment is not directly interacting with the learner.

The application "Visit the Unbuilt" was presented in the Second Multiplier Event in Eindhoven and the Third Multiplier Event in Paris, inside the possible applications of the @postasis platform framework. The results of this specific study were presented in the article "Integrating Digital Reality into architectural education: Virtual Urban Environment Design and Real-Time Simulated Behaviours" (Velaora et al., 2019).

This educational model initiates the learner to the notion of inhabiting unbuilt spaces that can be imaginary, academic projects of architecture, not accessible physical spaces. Also, we can simulate and observe the evolution of a possible virtual population of fictional entities. With this background in hypermedia knowledge and technical support, we combined our experience with architectural design during the auxiliary work in the Master's degree of NTUA.

Educational model 3 emerges as a sequel from the other two educational models, applying hypermedia representations to digital architectural environments. One of our principal educational goals was to propose models of architectural pedagogy that integrate new media and mixed reality applications. The third educational model can be considered semi-immersive since it is a standalone tablet application (sandbox game type).

This demonstration permits navigation and virtual inhabitation in a given 3D space, and the learner can navigate the environment as a single actor and spawn actors in the virtual environment. That "mechanistic" approach illuminates several aspects of design, such as visualizing public space in terms of the capacity of virtual entities.

The study about the random movement of virtual actors in the virtual space and the attribution of specific values led to design patterns that emerged from random movement based on avoiding the collision. We decided to apply the BII plug-in to the design proposal of a group[31] of architectural students, Master's degree (5th year), 2019, NTUA.

[31] Students: Paulina Saade, Giannis Georgkaklis and George Rompotis.

This learning approach belongs to the wider field of serious games since its purpose is to evaluate architectural design through interactions (virtual population) in the digital environment. This prototype is tailored to the digital experience of the participants.

The 3D environment affects the evolution of the digital population according to collision and time factors. The concept behind this juxtaposition of architectural design (residencies and landscape), with the hypermedia's representations, is to develop scenarios about visiting unbuilt architectural projects.

The students can observe the spaces formed between geometrical shapes and arrive at different solutions or conclusions about their proposal. However, the educative integration process is linear since the modelling stage precedes the application of the BII plug-in. Indeed, the automation of importing 3D environments for the virtual population needs to be integrated during architectural design. Nevertheless, we extracted valuable feedback about integrating such a digital tool from the small group of students who participated in this demonstration.

The interface manipulation remains "procedural", and although the user can easily navigate in the First-Person Controller view, it remains partially immersive. The visual aspect provided by the virtual inhabitation raises questions and observations about design patterns related to human behaviour and the design proportions. The "flânerie[32]" is a fundamental concept in architectural education, as initiated by Charles Baudelaire. First-person controllers' motion in the virtual environment, combined with the designer's intentions and machine calculations merged into MR, can provide interpretations of other possible perspectives.

The limitation of BII to produce specific patterns of the digital population can become an advantage when different environments are tested under the same conditions.

Since we analyzed the characteristics of the BII interface, we used the Spawn function for our experiment, given specific values (to distance and time).

To evoke the design studio's educational approach, we had to define the scale for the experiment (Chapter 8). The 3D model concerned the design exercise, and the project included the design of 200 residencies, plus the landscape/urban space design. A graphic and visual

[32] Concept of navigating the city introduced by Baudelaire.

compromise was necessary since the application (plug-in) could not maintain high polygons, 3D models.

The students modelled the environment in 3D, in a specific level of abstraction to keep the application "light", avoiding crashes and creating an explorable environment.

For this particular case study, the ground floor was considered essential for the aspects of the architectural synthesis. The ground floor is defined as "Navigation Mesh". It must be one continuous object, even if it contains surfaces in different levels and integrated objects such as sitting spaces and other urban equipment.

The anaglyph of the ground (relief) of the implementation site was designed with the help of Grasshopper software (dropping geometry) and simulated with media that support mixed realities. Nevertheless, we tested some realistic approaches to the site, but realism was not considered essential by the students. To obtain a particular graphical result, we combined 1:200 and 1:500 scales in detailing.

Virtual Presence

The students are partially immersed in their design by the constant movement of the (First Person Controller) viewer. The students can also look at the top, left, right axonometric and bird's-eye view of the model. Researchers claim that having all viewpoints "open" during design does not necessarily facilitate the design process. However, in this case, the bird's eye view, the top view and the observer view in the first-person perspective helped the learner evaluate their design after navigating virtually. The navigation permitted to look at the geometry of the environment from different viewpoints and angles.

With this application, we complete the sequel of experimentations of the webinar platform while addressing design issues such as geometry, volumes and navigation. These courses are published under the Creative Commons Licence and are part of the Open Educational Resources (OER).

Indeed, the virtual artistic laboratory can become a ground for discovery and exploration for architectural designs. The easy navigation inside students' projects can provide insightful feedback for the educational process. Learning is seen as a reflective, interactive process once the conditions are set and adaptive and interactive after the digital population.

The modular manipulation of the BII interface was familiar to architectural students that have tried Grasshopper. The students characterized the demonstration as little immersive and intuitive in terms of ease of use. Such an educational model can assist the design studio while providing new topological data and patterns according to design.

Experimentations 1–3 Summary

Briefly, the three examples based on the @postasis platform can help the architectural students to navigate, collaborate and interact by distance inside the 3D virtual environment of their 3D models. The platform is suggested by the Athens School of Fine Arts in collaboration with Paris 8 University, Argenia and Mad Emergent Art Center. Sometimes, artists tend to experiment with new media and visual representations more than architects do. Artists of visual and plastic arts also use certain aspects of game development. Such an approach promotes designers' distant collaboration but does not necessarily present a ground for design. The reduction of actors' movement as navigation about avoiding obstacles becomes more complicated when it comes to real-life conditions of human behaviour. Also, the graphical reduction and abstraction in comparison to realistic representations were necessary. Immersive environments are considered more appropriate tools for architectural students than the semi-immersive. The platforming of the learning process can create a new digital centrality that shifts the attention from the teacher to the platform.

The webinar courses provide basic knowledge about interaction such as virtual buttons, hyperlinking and digital population. Also, they present the technical expertise that architectural students can adapt without learning to code.

Webinar teaching approaches based on the 3D digital platform are similar to the VDS courses. However, this approach can be characterized by short-term life as learning approaches when it comes to the real design studio practice. This approach depends on huge informatics organization and skills (like VDS), which augments the cost and sometimes confuses the students. Such practice of a shared possible virtual laboratory for architects remains in the experimental mode for now.

The benefits that can bring to architectural design combine advanced informatics skills, modelling and graphic design. However, architectural students are already charged with a lot of design software knowledge, and architects will use only established platforms designed as virtual laboratories for architects. Seemingly to the artistic laboratory, we attempted to suggest a virtual architectural laboratory, where the learner can interact and find information about specific sites (narrative process).

Distance learning in 3D space can be amusing for architectural students to connect with other universities and develop activities in the same virtual space. The platform's integrated chat permits students to communicate, and architecture universities can apply for seminars and courses by distance collaboration. The shared experience enriches design by bringing new cultural elements and patterns.

The online platform is a 3D vessel to accommodate various educational approaches. For the tests that we conducted with the platform's assistance, we managed to create semi-immersive environments.

The informatics solution is web-based, and it is an interactive symbolic 3D space for multiple users (built for the server and client, Windows and iOs). However, the limited use of the @postasis framework leads to little motivation and future engagement from the student's side. Moreover, some performance limitations also require advanced technical knowledge and intensive system maintenance (server).

Finally, the demonstrations (1,2,3) attempt to raise awareness concerning virtual and physical presence through the first-person controller view.

Considering that this framework is experimental, we tried to apply that digital tool to architecture education. For the experiments participated the scientific Team of Paris 8 University, PhD students[33] of the MAP MACC-Lab and more than 60 participants during the two-day event had access to the virtual space of Parc de la Villette and the Folie Numerique, hosted at the building of Folie Numerique.

Our educational models 1, 2 and 3 are considered partially immersive since the user maintains contact with the physical environment during the interaction.

On the other hand, immersive environments, especially Augmented Reality, include aspects of the city (streets, coordinates, buildings, facades) that can help students directly identify architectural elements on the human scale. More and more portable devices support AR cameras.

[33] Malvina Apostolou and Louis Vitalis.

Educational Model 4

Mixed reality, where digital objects interact with physical objects.

The educational model 4, "Pixel People Data Parcours", derived from our collaboration with the MAD Emergent Art Center in Eindhoven, NL. We researched several ways of creating an AR application for the Dutch City. The demonstration "Pixel People" is built as an escape game, where the background is the environment of the actual town. The experimentation had the purpose of raising awareness to the participants about the use of personal data and hacking. The user is connected through the application with multiple external devices inside the Internet of Things frameworks, such as sensors to measure pollution, cameras, and lighting devices.

Concepts of "smart" city and smart house are tested through the benefits that connectivism offers. This application is subjected as an educational tool for architectural understanding about the surroundings. The observational ability augments perception and thus learning capacity. However, this tool is not a tool at the service only of architectural education. Pixel People is not a tool for architectural students only but is addressed to the wider public. It is presented here because it includes various interactions between participants and the city within the digital realm.

During this experience, we had to develop the AR experience based on a given scenario, but the choice of the development structure was left to us. It could have been an AR application that functions with markers, tracking images or QR codes. AR applications can be developed based on tracking images, objects, QR codes, and GPS locations in terms of technical knowledge. We considered that connecting AR through GPS locations would permit the participants to reflect on the plan of more "realistic" conditions. At the same time, specific points of the walk provide multi-city open-air virtual exhibits. We developed this application with a presenting interest from an architectural point of view, liberating the user by tracking references and connecting the learner to the location of the physical presence. This is why we chose to investigate the direction of AR applications based on GPS coordinates, to investigate the optimal way of placing the scenario of Pixel People into the immersive experience for the users.

This experience provided a solid technological background and informatics assistance to develop a script that facilitates the association between locations and digital content in relation to ARkits that exist online. This script permitted the creation of multiple interactions between the participants and the physical environment of the city. The participants walk the city through solving quests through a screen-based interaction (tablets) with the installed application.

The movement of humans and their behaviour in contradiction to the virtual actors presents an increased complexity naturally compared to virtual actors (Educational Models 2 and 3). In the case of AR, the GPS coordinates system of the user's position participates actively in the immersive experience. The coordinates system of the user merges with the coordinate system of the computer and the natural environment. The learner becomes aware of a hidden digital reality like a parallel reality based on data visualization.

General About AR

In video games (like PokémonGO, 2015), the AR experience can often be quite dangerous if the user ignores the real aspects and all distractions. Immersive virtual environments of AR are risky environments for the user if the user does not maintain contact with the real issues of an environment.

Apart from a profound knowledge of AR application development, Pixel People permitted us to imagine an AR tool customed for architectural design needs. Architectural design is directly related to a physical environment, either city or countryside, and the city itself presents fundamental knowledge about architectural conception.

AR reveals content that would be unnoticeable by students, also train the eye in natural size proportion through real-time see-through lenses. The educational models presented are part of a sequel.

The "play the city" theme is apparent through this escape-the-cyberspace game. The digital city is not seen as merely a programmable environment (smart city) but brings into the dialogue of Mixed Reality media the topological characteristics of the place. This approach bridges the designer with the real factors of their design proposals. Apart from being a powerful representational tool, AR can orient students to navigate the urban environment according to specific points of interest (an instructional learning process). Tutors and students can be inspired by such an approach as the experience surpasses the strict limits of architectural design. Wandering, observing and memorizing, parts of the physical environment benefits the architectural reflection and thus conception.

Inside the curriculum of a semester, for a possible academic appropriation of this approach, the role of the teacher is to prepare a tour in AR at the site of the project's implementation before the exercise starts. The teacher's challenge is to value this method's decision-making functionality (compare, enjoy, learn about locations), as the tutor pinpoints an intuitive way to perceive, navigate, and design the city.

(AR) Big companies like Apple, Google and Facebook invest in mixed or digitally blended realities, preparing the ground for new media applications. The public seems flexible in adapting new media, especially those that increase the connection between reality and the Internet. Education might fall behind the curve if researchers ignore the massiveness that the phenomenon of immersive media may obtain in the future. AR will not necessarily improve design, but its representational and communicate benefits that presents can be among the future students' preferences. By interaction and dialogue, teachers and learners develop a framework about the dangers and limitations of this approach. Mixed Reality media can alter architectural conception, and design remains a subject for further research that we tried to access in Application 5.

AR is more than a city guide tour, and it gradually becomes a visual 3D tool for decision-making since it can visualize many different options and select accordingly.

To sum up, according to our experience (empiricism), this educational approach shapes a theoretical and practical approach to applications of AR, based on learning approaches of connectivism, Internet of Things and smart city tours, investigating the circulation and the visualization of data. The academic scope tends to see AR as a media of selection or decision-making to help learners better collaborate and cooperate.

AR is now supported by cameras, projectors, data gloves, touch screens, glasses and mobile devices in the long run, which makes it an easily accessible tool for architects. Different approaches might be developed, which are also defined by the technical setup.

Educational Model 5

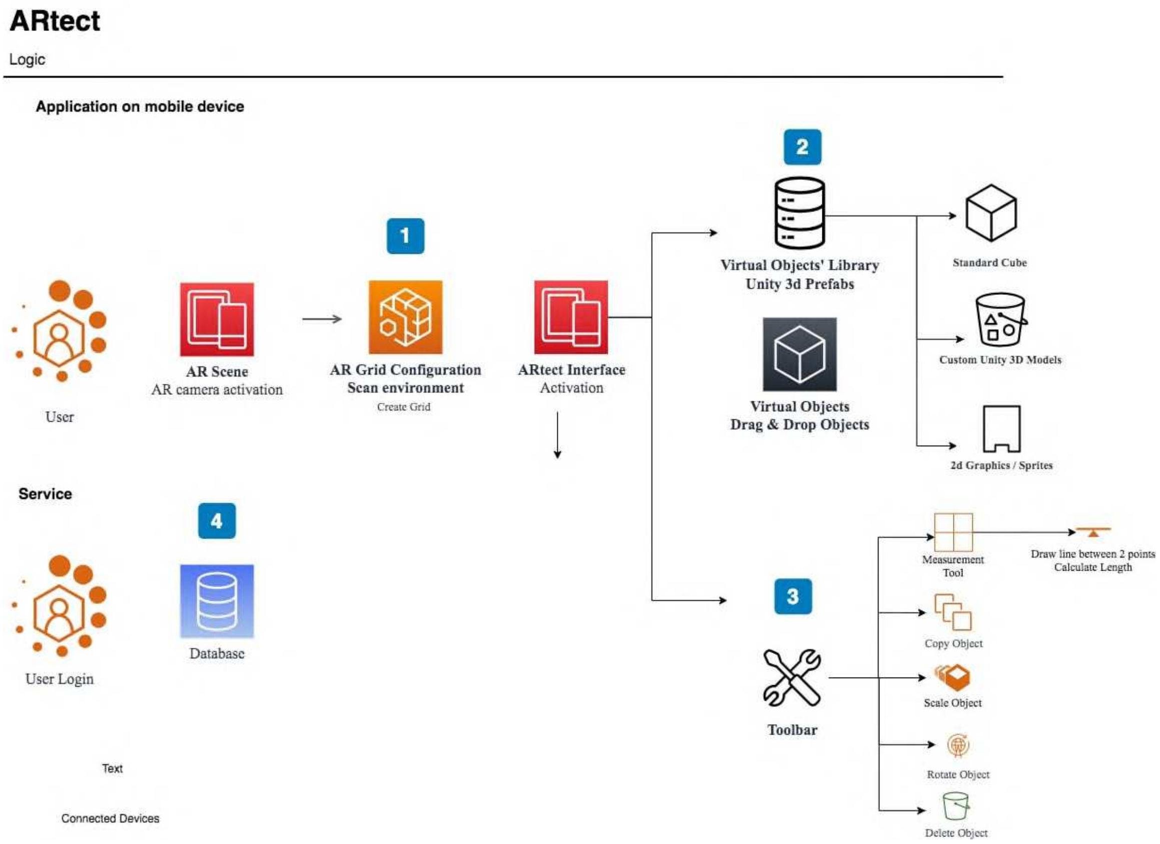


Figure 114. ARtect Diagram. Logic and steps.

The main idea of ARtect design (Fig. 114) is composed of these main elements:

1) Grid configuration
2) Virtual object library
3) Toolbar inspired by CAD properties design
4) Database service

The learner designs in situ and collects the 3D models shared in the online server library. This tool is presented at the IEEE WS4 conference in London, 2020, in the article titled "ARtect, a prototype for architectural design in augmented reality" (Velaora et al., 2020).

ARtect educational model:

- Combines visual and haptic information about object properties, spatial coherence with Six degrees of freedom 360°
- is designed as a digital AR toolbox for architects (solving toolbox)
- It cannot yet support fluid lines and sketches
- Permit distancing and reflection on one's model.
- Enhances adaptive versatility

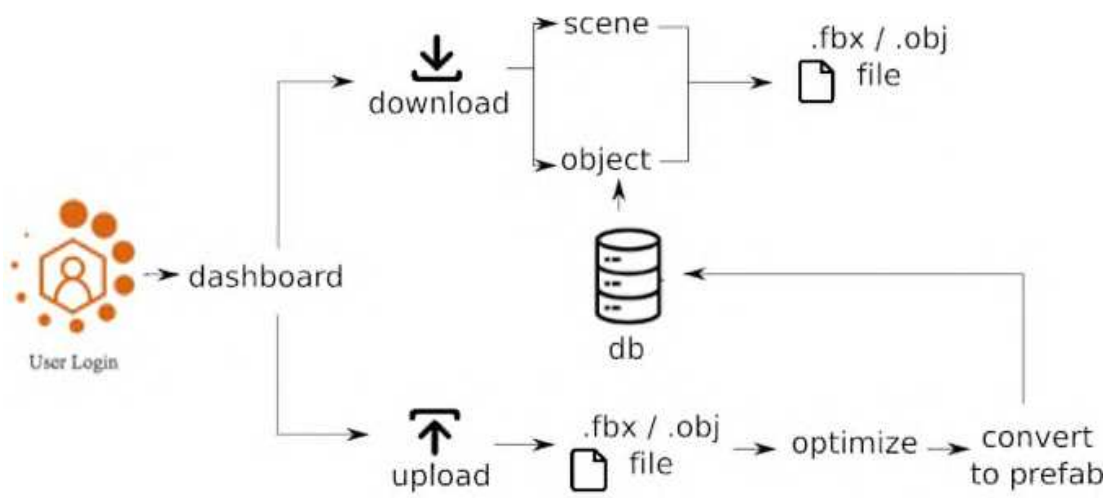


Figure 115. ARtect concept for building digital application for architectural design. Innovation in AR function about designing in 3D immersive space combined with CAD.

The innovation of this AR prototype is that the learners can store and download their 3D sketches as virtual scenes on their computers to continue modifying their models with traditional CAD tools (Fig. 115).

The last of our experimental digital developments is Application 5, named ARtect, which, as mentioned, derives from the terms Augmented Reality and Architect. The concept of this application was based on creating a tool familiar to the architectural student.

This digital application prototype aimed to recreate the basic design commands provided by CAD in Augmented Reality, such as select, copy, multiple copy, move, rotate, scale, measure distance and delete an object. These commands give the possibility to the user to create volumetric sketches in real-time in geographical locations. Furthermore, ARtect (Model 5) has a dimensioning tool for verifying the scale of imported objects; we claim that is the model that helps the most for understanding the scale and proportions of 3D space.

Many researchers concerning Augmented Reality and architectural design focus mainly on indoor activities, like lighting, temperature, and accessibility that can be easily controlled. Our prototype augments 3D objects in real-time based on geographical positioning coordinate system (GPS) collected by mobile devices. It is designed to function both outdoors and indoors.

The development challenges in this prototype were various. Specifically, the part provides a virtual environment for modifying 3D objects in the three axes (x, y, z). The main issue was selecting a 3D object in a 2D screen that could be moved in depth. Also, the configuration of a stable ground grid to anchor 3D objects eliminated the limitations concerning the accuracy of augmentation to improve the flow and the performance of the immersive learning experience.

The purpose was to liberate the student in the 3D physical space and use it for design. Our method aims to motivate the learner to construct virtually 3D sketches in different locations, according to the learner's preferences. As the development of this tool started in 2020, we could not conduct additional testing with students due to restrictions outside of the educational field. The academic year of 2020–2021 was characterized by distance learning and limitations in circulation (lockdown). We experimented with the tool with only smaller independent groups. Therefore, in terms of integrating this approach inside the academic curriculum of architectural design, our investigation was limited. However, we consider this last experimentation has the most to offer in the learning process of the design studio.

This application provides positive feedback about understanding and perceiving the proportions of space. In the default mode of Application 5, the learner can fill the space with cubes of 1 m (as virtually augmented content). The application features permit the user to navigate the virtual and real space simultaneously, immersing the designer in its actual decisions.

A learning process can be described as both productive and communicative since the experience of space in 360° degrees of vision can help learners communicate their intentions and goals. The interface allows instant modification of the virtual environment, increasing productivity since it offers multiple views from different angles. This method aims to facilitate students that deal with difficulties in scale understanding, detailing and zooming in and out of the architectural design.

As a learning process, it is designed to direct the learner to the physical environment or site of implementation. It inspires a realistic approach to the proportions and scale of the surrounding buildings. We find that such an immersive environment can become an automated process when applied in DS in the future. The students using portable devices do not need to learn to code or have other tasks in mind other than design and volumetric synthesis since the application also functions in a stand-alone offline mode.

We developed this augmented reality prototype based on GPS location as portals to the immersive experience. Our goal remains to give freedom to the learner, in terms of design, without increasing their cognitive load to learn extra software. The architectural student is already overwhelmed with the amount of knowledge that has to absorb, such as manual design skills, software design skills (CAD), physical model production, history and theory. This method can be individualized and is affordable for the students since we value tools that we use in everyday life, such as mobile phones.

Some designing scenarios that are to be excluded can be tested virtually and not in physical models in scale (maquettes). The digital prototype is designed as a toolbox (solving toolbox) for architects and aims to facilitate manual and digital design transition. It permits distancing and reflection on one's model without forcing an absolute design precision since the beginning of the conception; it can become a tool of spatial synthesis and decision-making for the early stages of design.

In the future, more features such as fluid lines, geometries, subdivisions and materials can be added to this application or similar AR applications. The difficulty for architects is communicating with developers, and vice versa for this type of mixed media integrated design. The author claims that big CAD companies such as Autodesk and Graphisoft can soon adopt Mixed Reality media approaches of AR in the future.

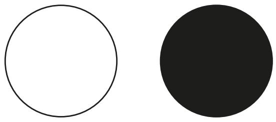
We claim that academics should be pedagogically prepared enough to integrate immersive virtual environments accordingly during the learning process. Lastly, more research needs to be conducted towards the direction that combines neuroscience and architectural design. As the human nervous system combines visual and haptic information about object properties, such occurs with AR. ARtect provides visual content through screen-based haptic experience and movement in 3D space. The spatial coherence of architectural conception is essential to be perceived concerning the physical environment.

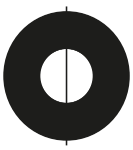
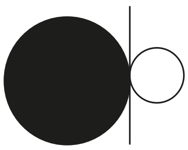
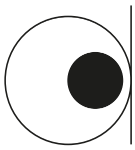
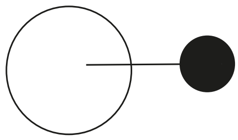
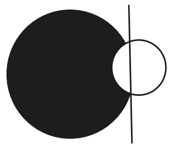
For the future, we suggest that neuroscientists, developers, artists and architects' combined knowledge can lead to powerful tools with augmented reality media form.

11.3. Synthesis

We compare the five educational models that we suggested. We attempt to evaluate and rank these educational models based on the nature of the applications we developed.

Table 7. Comparison based on schematic representations between virtual and real.



Comparison Educational Models				
webinar course on 3D platform			augmented reality	
Folie N5	BII	Visit the Unbuilt	Pixel People	Artect
 Model 1 Folie N5	 Model 2 Behaviour Interactive Interface	 Model 3 Virtually Real Visit the Unbuilt	 Model 4 Pixel People	 Model 5 ARtect

Application 1 presents an experience where the natural environment includes its representation in the digital media. Application 1 is an example where reality includes virtuality (Table 7). Application 2 is a plugin, an interface that also presents a semi-immersive experience. The limit between virtual and real is tangible through the computer's screen and mouse inputs (Table 7). Furthermore, Application 3 refers to the physical models produced by the students during the design studio and transferred in the virtual environment. The educational principle of fabricating architectural models with cartons and other materials is transferred in the virtual environment. This application as a digital environment includes the physical environment in scale. Since the physical object is not fabricated on the human scale, the digital environment includes the real (physical) environment on the scale instead of the opposite situation (Table 7), as in Application 1, where the park and the building are on the human scale. Application 4 connects virtual and real aspects concerning internet connection and distance connection (Internet of Things). This approach of the limit between digital and physical is linking (Table 7). However, this approach associate's interactions only in instructed locations. Application 5 is an AR application that merges virtual and real content through the glass limit (screen) (Table 7). These are schematic approaches to understand the different natures and compositions of Mixed Reality media and the limits between the real and the virtual environment.

In addition, we attempt a ranking concerning the levels of immersion evoked in each of these applications (Fig. 116).

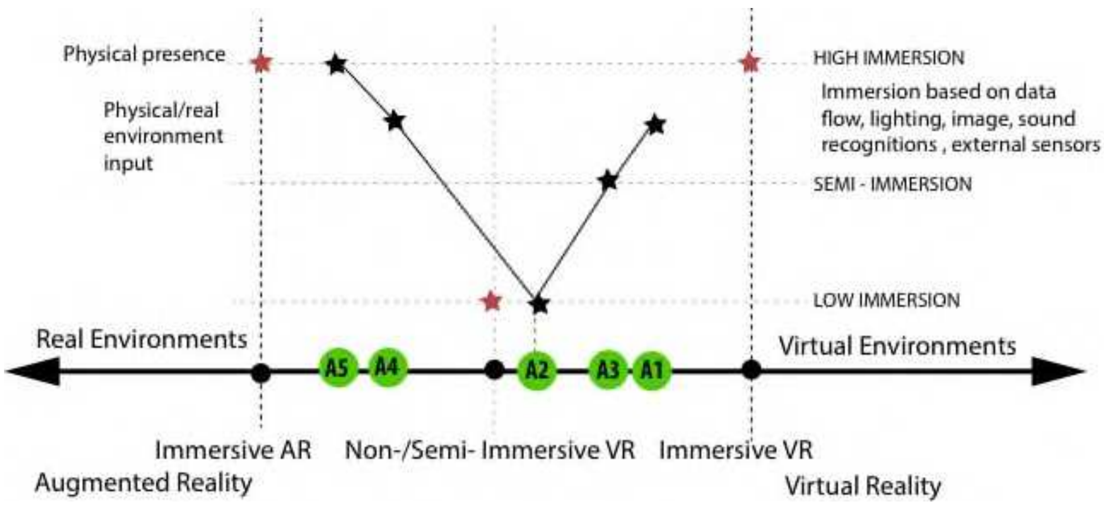


Figure 116. Identifying levels of immersion in applications based on the conversational framework with students, participants and teachers.

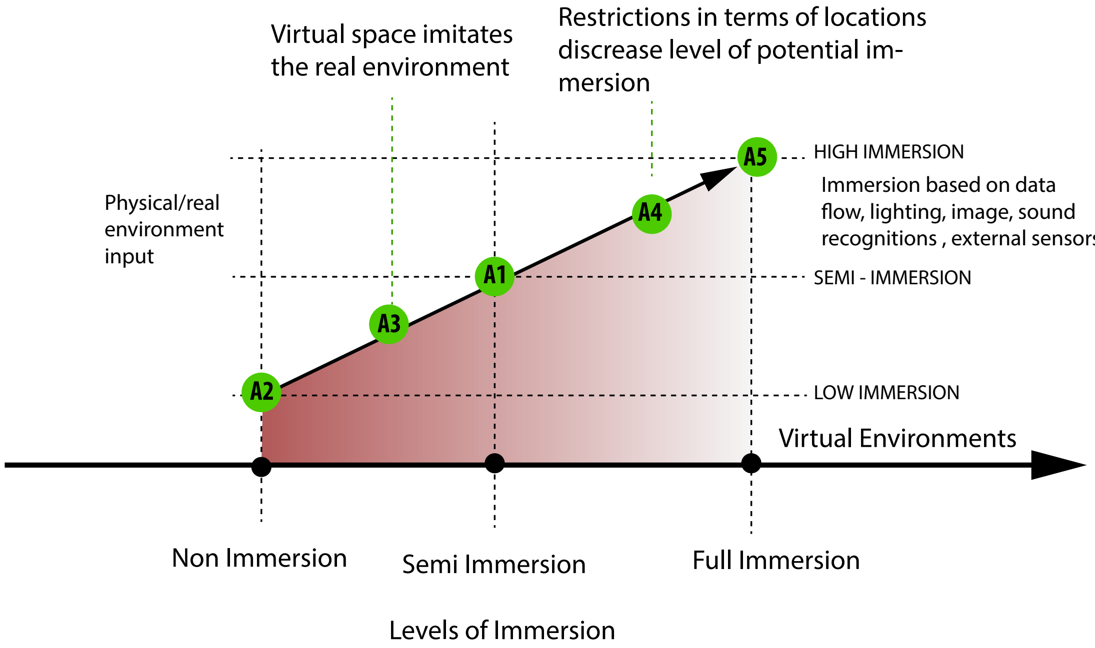


Figure 117. Levels of immersion and experimentations. From lower to a higher level of immersive, A1-A5 experimentations.

AR Applications 4 and 5 are fully immersive. However, Application 4 met some restrictions in terms of locations (as there were on a specific route). Application 2 concerns the Behaviour Interactive Interface, and since it is a plugin (nature of media) can be seen as a low immersive or semi-immersive tool. In the same train of thought, Application 3, an application of BII in the Design Studio, can be seen as more immersive than the plugin itself but less immersive than Application 1. Application 1 presents a semi-immersive environment first because of the simultaneous presence of the user in the real and virtual environment of the Parc de la Villette. Secondly, we used large screens for the interaction. Therefore, we conclude with the ranking concerning the levels of immersion from the less to the highest immersive application (Fig.117).

We present Table 8, an overall synthesis of the educational models based on the number of participants, the intellectual output, applications, and pedagogy space.

Table 8. Comparison of educational models 1–5.

Comparison Educational Models					
Title	webinar course on 3D platform			augmented reality	
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
	Folie N5	BII	Visit the Unbuilt	Pixel People	Artect
Type	**Semi-immersive demonstration**	**Semi-immersive serious game**	**Semi-immersive serious game**	**Immersive escape game**	**Immersive application for design**
Number of Participants	60	60	60	45	10
Intellectual Output	E-book	Installation	eCAADe publication	Event	IEEE Publication
Built applications	Application for client/server	Multiuser application	standalone application	Internet of things AR application	Offline playmode and connexion to server
Pedagogy space	webinar course	webinar course	**Design Studio Intergration**	AR, a city tour	AR, a city tour and design studio

Educational Model 3 is the only one that was integrated into the real practice of Design Studio. However, Model 5 has all the potentials to be integrated, but since it promotes on-site participation of students, we could not test it in the DS of the semester 2020-2021 due to the imposed lockdown. By default, AR applications based on GPS location demand physical presence on the implementation site; therefore, the two categories we presented demonstrate different benefits.

In addition, we evaluate our models about learning criteria (individual, in groups, by distance) (Table 9). Furthermore, based on the learning process and the activities developed, we explore the different qualities of these educational models.

Table 9. Comparison of educational models 1–5. Characteristics and processes.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Criteria Learning					
1. Individual	√	√			√
2. In groups	√	√	√	√	√
3. By distance	√	√			
Learning Activities [Design features and Media forms]	Narrative & Communicative	Adaptive	Productive & Reflective	Interactive	Interactive, Productive & Reflective
The method followed about the physical & virtual 3D space relationship	Imitation/Digital Reproduction	Imitation	Imitation	Simulation	Simulation

The difference between the two approaches (webinar courses with 3D platform and AR) lies in how we perceive and experience space. In the first case, we have the Newtonian hypothesis, a system of Cartesian coordinates, and each object has an absolute definitive position according to a system of reference. On the other hand, space is defined by physical objects and consists of an infinite and symmetrically empty area.

Architectural drawing and sketch are representative means that simulate actively technical aspects rather than imitating (mimic) reality. Imitation or digital reproduction of reality can be a subjective choice of the designer but does not defog the nature of architectural tools. As Augmented Reality tends to have similarities in simulation in representation with architectural layering thinking, we lean on the approach AR method. The features such as immersion, 360° view and six degrees of freedom during the design experience also highlight this conclusion.

Furthermore, we present Table 10, which demonstrates the time of preparation for each one of the applications. Moreover, as learning processes, Model 2 and 5 can be automated even merged in the future. That means that the learners can augment their models virtually and/or automatically generate a virtual population. Models 1, 3 and 4 are singular experiences that cannot lead to a general automated process. The automated process can decrease a lot of time of preparation the student and the tutor. Models 1, 3 and 4 demand a lot of preparation from the tutor that surpasses the limits of architectural knowledge.

Table 10. Comparison of educational applications 1–5. Characteristics and processes.

Duration Characteristics	**App 1**	**App 2**	**App 3**	**App 4**	**App 5**
Time of development	Folie N5	BII	Visit the Unbuilt	Pixel People	Artect
Average time of experience	15 min	15 min	15 min	20 min	20 min
Time preparation for the students	6h	6h	1h	20 min	20 min
Time Preparation for the tutors	3 days	5 days [the process can be automated]	7 days	3 days	7 days [the process can be automated]

Table 11 presents media forms, learning experiences, and methods used to deliver the educational models. Model 1 corresponds to a *communicative* and *narrative* learning experience through hyperlinks; Model 2 corresponds to an *interactive* and *adaptive* process about the conditions and attributes we add. Model 3 is an *adaptive* process since we inserted standard conditions. Model 4 corresponds to a fixed scenario and pre-defined interaction, which is a narrative interactive learning process. Finally, Model 5 is a productive and communicative learning process. All educational models are interactive (Table 8).

Table 11. Media forms, learning experiences and methods used to deliver the educational models.

Educational Models	**Learning Experience**	**Methods**	**Media Forms**
Model 1	Attending, apprehending, exploring	Seminar online conférence, web ressources, vidéo	Communicative, Narrative
Model 2	Experimenting, practising	Simulation, virtual laboratory	Adaptive
Model 3	Articulating, expressing	Essay, product, animation, model	Adaptive
Model 4	Exploring	Web resources	Narrative
Model 5	Investigating, exploring, discussing, debating, articulating, expressing	Library, web resources, seminar, online conference, product, model	Communicative, Productive

In addition, we present the evaluation of these applications that formed the specific educational models, based on the feedback we had from the participants and the possibility to assist the Design Studio learning process. It appears that Models 1, 3 and 5 were characterized as intuitive, an asset that increases motivation, positive emotions and student's engagement during the experience (Table 12).

Model 1, Model 3 and Model 4 can be used once the modelling process is finalized to serve at the ending stages of spatial conception. On the contrary, Model 5 can assist conception in the early stages and initiate the student to basic CAD commands.

Table 12. Evaluation of the applications A1-A5 for assisting Design Studio.

	App 1	App 2	App 3	App 4	App 5
1. Automated process possibility			√		√
Educational Process					
2. Conversation	√		√		√
3. Architectural Design			√		√
4. Student's engagement	√		√	√	√
5. Ease of use Intuitive	√		√		√
Architectural Features					
6. Development of interactions with the city				√	√
7. Scale adjustments	√	√	√		√
8. Dimension/measure			√	√	√
9. Viewpoints [top, left, perspective views]		√	√		√
Stages of spatial conception					
10. Beginning [Sketching, draw lines]					√
11. Production [Decision Making, make improvements]		√	√		√
12. Finalization [renderings, representations]	√				

In addition, we interrogate these applications under the prism of fundamental issues in architecture (structure, natural light, massing, plan to section, circulation to use space, unit to the whole, repetitive to unique symmetry and balance, geometry, additive and subtractive and hierarchy) to observe what would be more suitable for architectural students. We observe that Model 5 corresponds better to architectural learning (Table 13).

To sum up, according to our analysis and synthesis, we suggest a ranking from the most performant to the least performant educational model for integration in the architectural curriculum, as follows:

a) Model 5
b) Model 3
c) Model 1
d) Model 2
e) Model 4

The webinar platform is experimental but remains attached to traditional learning methods of connectivism. On the other hand, mixed reality media blend digital with reality.

We are concluding that AR can be a powerful tool when processes are giving freedom to the user. Model 1 is a strong example of transferring the real environment into the digital and observing the difficulties of digital reconstruction. Finally, Model 3 is the only integrated model in the academic curriculum so far.

Virtual immersive or semi-immersive environments should assist the transition of manual design to digital CAD design to help students understand their design strategy.

Similar Educational models include an Application followed by Documentation of Theoretical and technical background, suggesting Mixed Reality applications can be the future of architectural teaching**.** The absorption of AR in architectural education seems quite inevitable in the future as it augments and organizes space.

Table 13. Evaluation based on precedents of architecture.

	App 1	App 2	App 3	App 4	App 5
Title	Folie N5	BII	Visit the Unbuilt	Pixel People	Artect
Type of virtual environment	From real to virtual, Interpreting reality with geometries	Virtual laboratory, Virtual entities, Interface	From real to virtual, Inhabiting maquettes, Interface	Coexistence virtual and real environment, Data flow, Interface	Juxtaposition real and virtual environment, Organizing, dimensioning virtual geometries in real space
Environment of interaction	in situ [virtual & real]	Virtual	Virtual &3D physical models on a scale	Specific location Eindhoven	Any location in situ
1. Structure	√				√
2. Natural Light			√	√	√
3. Massing	√	√	√		√
4. Plan to section to elevation	FPC view	√	√	FPC view	FPC view
5. Circulation to use of space	√ [levels and floors]	√	√	√	√ [body movement]
6. Unit to whole	√				√
7. Repetitive & Unique		√ [randomness]			√
8. Symmetry and Balance					√
9. Geometry	√	√	√		√
10. Additive & Subtractive		√	√		√
11. Hierarchy	√	√	√	√	√
Overall evaluation √	14/26	13/26	17/26	7/26	23/26

The overall evaluation of 26 points, includes the Tables 9, 12 and 13.

Conclusions

This is a thesis in co-supervision between the Conservatoire National des Arts et Métiers of Paris and the National Technical University of Athens with the participation of the Ecole Nationale Supérieure d' Architecture de Paris la Villette.

The context of the thesis is the teaching of architecture, particularly the teaching of the architectural project with the assistance of Mixed Reality media (Virtual Reality and Augmented Reality). The teaching of the architectural project is a particular learning process that focuses on practice. The starting point for learning in the studio is a design problem that architecture students are likely to face as future professionals. The teaching methods generally used in these studios belong to the category of Problem-Based Learning. In this particular training context, students may have difficulty acquiring certain essential concepts.

The starting point of our query is based on the hypothesis that digital tools could facilitate the learning of certain architectural notions. Unlike other disciplines, there is no real digital transition in the teaching of architecture (from manual to digital drawings). Although widely used by architects in their professional activity, computer-aided architectural design (CAD) and 3D modeling software have not really had an impact on architectural design education (Al-Matarneh & Fethi, 2017). In particular, in project studios.

The teaching of the project is generally based on traditional pedagogies, especially in the early years of studies, when digital technology is rather perceived as a tool for representing a project conceived traditionally. Teachers prefer the use of manual drawing, especially for the ideation phases. Digital technology is even often perceived as harmful to learning the perception of space and the appropriation of spatial scale and proportions. Teachers often argue that the intensive use of design and illustration software can create a cognitive load that paralyzes or delays learners' creativity.

In professional practice, CAD and graphic design software is mainly intended for the production of conventional representations of projects designed in the traditional way and to facilitate communication between the various actors in the construction field (architects, engineers, builders, etc.). Ideation design is usually not done in CAD (Dorta, 2007). In addition, traditionally, architects design on a specific scale that they define at the beginning of the design. This process reveals the relationship and analogies between the design object and the designer. With the exhaustive use of CAD, the learner designs in an infinite environment without pre-established scales and in an unlimited space. Repeated "zooming" on the design object can destabilize the students and lead them to conceive on an often unknown scale.

This suggests a need for tools that allow students to walk around and visit their architectural models during the design process in order to better perceive the spatial characteristics of their projects. But current design tools, such as CAD and illustration, limit 360 ^{o}degree views in the architectural design project. Although CAD models offer design accuracy, they sometimes reduce designers' perception (Stacey & Eckert 2003). Aware of this problem, university researchers in France and the United States have experimented with software called "game engines", such as Unity 3D and UnReal Engine, used to create video games, Virtual Reality (AR) and Augmented Reality (AR) applications for teaching architectural design (Lescop and Chamel, 2020). The combination of digital technologies such as CAD, graphic design, illustration, texturing, mapping and video game software can make architects' models interactive. The interaction includes real-time virtual navigation in the architectural design (virtual immersion). This thesis can be seen as a continuation of this research work. Our goal is to participate in the development of pedagogies using digital tools that are adapted to the learning of the project, especially during the first years. "Can the use of immersive environments, as we encounter them in VR and AR applications, improve the learning process of architecture?" is the main question of this thesis.

We explored digitally assisted architectural education methods, particularly for the Design Studio. We focused on the media provided by Mixed Reality and Immersive Virtual Environments. Teaching in Architectural design has the tendency to incorporate mixed reality approaches, where traditional architectural projects coexist with hybrid methods and novel technologies through media oriented towards computer design.

In the past, in medieval times, there was not a nominal creator of the architectural project, as we have later in the education of architecture and arts. The printing press machine, for massive production of printed text and images, revolutionised the representational ecosystem of that time. Later, the arts of photography and cinema emerged, with the use of cameras and special lenses. The printing device and the camera have a huge impact on the production and communication of design and promoted individual identity, which was shared with the public.

Therefore, other than the pencil and paper, the frame and the camera (specific viewpoints) affect how we design and perceive space, natural environment, private and public space. Researchers and professors claim that nowadays we come across another “media—break”, as it happened in 1440 with Gutenberg’s printing machine, the evolution of glass and the technology of cameras and lenses. The AR cameras which are embedded in portable devices such as smartphones permit the projection and entrance into a 3D digital world.

Each design studio is unique as an architectural exercise of design also its progress. Then, the design is evaluated according to the professors and the students that participate accordingly. The design project demonstrates the fundamental practice for the teaching of architects as it has a dominant role in the academic curriculum. However, our approaches can be further integrated into urban planning and in the history of art and architecture, apart from the course of Design Studio. It is imperative that studies in architecture open to other disciplines, such as creative activities, informatics, sculpting, robotics, and developing projects in common.

The mixed digital reality does not necessarily make older types of educational processes disappear but renews educational types that were weak or had faded away over time. OER (Open Educational Resources) reveal a reconstructive process towards this direction of regenerating open-source knowledge. The shared communal ownership led to the emancipation in the creativity of young designers. The open-source systems led to the development of new strategies of collaboration for the artist and the architect. One of our first conclusions is that hybrid learning models with the physical and digital presence of the students can be beneficial in terms of creativity and interactions during the learning process.

The tools and the technology the architect uses for design have an essential role in this study for the teaching process. The physical models in scale and the architectural drawings (plans, sections, elevations) are conceptual devices that reveal information about the geometrical space representing a type of 3D reality in scale.

The architectural drawing is a convention to simulate space, as orthogonal projections, such as plans, sections, elevation, map, etc. However, in reality, we rarely see a "plan" or a section, and therefore, it is important to clarify that the architectural drawing *simulates* several visual conventions rather than *imitates* reality.

The era we traverse when the thesis is conducted is a transitional time for design media as it happened with the printed book. We observed that in the last years, there is a radical reshaping in the forces of production of any type of art, meta-versing from the digital environments into the real environment, via virtual immersion. Henceforth, we highlight that the context of the research had to overcome two major challenges. On one hand, the thesis is international, shared between two EU countries. This demanded a significant part of administrative work. In addition, many documents had to be translated into all three languages (Greek, French and English). The choices that we came across in each environment are similar, and connecting pedagogies from different points of view was a learning experience. Time management, travels and the resources needed for this type and framework of research are crucial factors that were valued during the process. The supervised thesis is a decision and a challenge, that clearly demands a lot of involvement.

On the other hand, the next challenge lies in the unstable ground of the technological and scientific field, since the evolution of new media was massive during the years 2017–2021. Social media like Facebook in the dawn of Metaverse, the increased use of Instagram, the advancements of sophisticated hardware, and the sanitary crisis of coronavirus, revolutionize the daily use of the Internet. It permitted the development of questions in times of uncertainty. This challenge permits us to develop a mentality about mixed media realities which makes the research intuitive. Devices and experiments on the effects of Mixed Reality are in the first stage of evolution. One of the challenges for this research was the development of applications in parallel with architectural thinking. Admittedly, mixed reality media cannot fully improve the learning in question without additional tools integrated.

We hypothesise that immersive digital could assist complementarily the teaching of architecture. The use of mixed reality applications such as VR and AR during the design studio can become teaching tools that facilitate spatial education and the evolutionary transition between traditional and hybrid teaching methods. Our hypothesis consisted of setting learning experiences with immersive and semi-immersive environments for architectural students has been validated.

There are several different approaches to integrating immersive virtual environments employed in studio design, but there is still a lack of experience with those tools. Given this lack in the bibliography and practice, we try not to propose a single educational model with immersive media.

Our research traversed the fields of video games, webinar courses, installations and the development of AR experiences. We experimented with OER and the development of digital applications. We argue that Augmented Reality can become an indispensable tool for architects in the future. In addition, the research opens the dialogue about the use of AR and VR applications for architectural education. We conclude that AR, which is not a bad thing for architectural education, will be used equally with VR applications in architectural studies, although for now, AR applications are less developed than VR tools.

Our research method aimed to test different applications of mixed realities designed to teach architectural design in project studios. We have thus, built five pedagogical models and sought to evaluate their possibilities and limitations. We identified a lack of AR tools for the design studio, and thus, we prototyped the example "ARtect" as a guideline for future research, after a series of other digital experimentations. At this stage of research, the tool once in operation must be individualized, for each group of students. The evolution of teaching with AR in architecture depends on developing these tools in the future and, of course, on teachers' digital expertise. Moreover, the process of integrating immersive environments into the representation continuum of architecture, digital creation and architectural education cannot be linear. This means that the process of designing does not begin with the pencil and then continues to the digital with CAD, but in this process, we cultivate the tests of the architectural designs in *immersive simulated environments during the design process, not as a finality of the project.*

Immersive environments appear to shape transitional educational spaces for architectural education between traditional manual design approaches and CAD. The integration of these types of tools can lead to a total reform of architectural education, through touch screens, see-through wearable devices, data gloves, etc. This thesis in architectural design, urbanism and environment argues that *immersion* is a new perceptional state for measuring architectural scale. Immersive environments merit to be examined from the architectural point of view, as they give form to aesthetics, properties and alternative universal scenarios of dwellings through interaction.

Our methods cultivate sensibility and attention to the elements of the environment (e.g., urban landscape, natural environment, lighting, air quality, etc.), and in parallel, the learners obtain the cognitive conscious activity of understanding *scale* and *dimension* in the physical environment (physical immersion), also in its design and representations (mental immersion).

The contemporary educational approaches in art (e.g., Generative Art), architecture, environment and technology, process the conditions of the learning experience with the development of ways and methods that involve more the senses during the design process. This directness of perception through senses and emotions, which is lacking in the printed text and drawings, enables new media to give birth again to improvisation during educational experiences. Expression and creativity possibly bring the universe of senses closer to the intellectual world through virtual reality and global networking. The merge of art, technology and science that digital media bring, lead to a repositioning of metropolitan design and urban needs, in everyday life, also affects the role of the architect.

For example, drawing by hand implies the direct connection between pencil and paper. Nowadays, self-phones and the computer's mouse are indispensable tools daily for an architectural student. The medium is constantly attached to the designer's body during the sketching process. The movement of the student's gesture directly expresses the design intentions. With the freehand design, there is no other cognitive intermediate stage between one's intention and the ability to express and visualise design. The act of design is tied with the five senses in particular of touching, seeing and hearing. The design tool such as the pencil is a transportable tool because is a tool of description, explanation and problem-solving. On the contrary, the arrival of the daily use of computers created physically expressional limitations, while expanding the intellectual (mathematical) expression. Architectural studies have undergone transformations through the evolution of representation design tools and technology.

Due to these transformations, AR and VR can shape educational spaces. The representations that are mobilised by design professionals (scaled models, technical drawings, Computer-Aided Design [CAD] models) do not always make it possible to evoke the characteristics of the project effectively (Van de Vreken and Safin 2010; Dorta, 2019).

Therefore, Augmented and Virtual Reality applications, can further expose aspects of the design solutions that are not easily perceived on drawings. AR and VR applications must be conceived as spatial tools that enable the conditions, provide the materials and the tools for architectural problem-solving design. Immersive Virtual Environments (IVEs), inscribed in the general ecosystem of representation, present a significant device for exploring design, fabricating and learning. Digital media, in the larger framework of digital ecologies, are not just tools but function like entities that we use to build knowledge.

The traditional DS tools such as paper, pencil, and carton models have been enriched with digital means, as online platforms, webinar courses, immersive and interactive virtual environments. In addition, current difficulties during spatial conception and synthesis have led to various digital tools for architectural design to help cooperation and co-conception by distance in real-time immersive virtual environments.

Immersive Mixed Reality media applications offer the possibility of synchronous and asynchronous teaching design methods, as they allow the visit on a human scale in real-time. The invention of the Internet and the possibility to defy geographical distance is transforming the profession profoundly by augmenting the gap between studies, market and profession. How well are students prepared to deal with real market demands before graduating from the school of architecture? The contribution of this research describes more models and virtual environments of digital experiential synchronisation, that can be used in education about learning architecture and architectural design. The introduction of immersive tools during architectural design has helped to reshape the modalities of the development of new modes of representation (Dorta & Taouai, 2021).

Hybrid reality learning models (coexistence of physical and digital educational space) provide immersive environments that allow designers to work alone or in teams with immersive 3D sketches at scale (Dorta & Taouai, 2021). The use of immersive environments has shown several benefits, as they improve the understanding of proportions and scales and the evaluation of design proposals (Beaudry-M et al. 2018, Dorta & Taouai, 2021). Certainly, immersive tools such as Benchworks (Seichter, 2004), Collaborative Design Platform (Schubert et al., 2016), Luminous Planning Table (Ben-Joseph et al., 2001) are examples of the possible use of mixed reality in the project workshop.

In addition, there are hybrid platforms and CAVEs, such as Hyve-3D (Dorta et al., 2016), Simulation Lab (Kalisperis et al., 2002) and Coraulis (Milovanovic et al., 2017) which are immersive systems that facilitate the co-design and creation of models in Mixed Reality, allow interaction using portable devices. This type of digital tool is designed to transform the Design Studio room into an immersive space. Research has shown that methods based on AR (Augmented Reality) improve the effectiveness of learning in education in general (Oluwaranti, 2015).

Research also shows a higher degree of satisfaction through AR technology and improved engagement and motivation in architectural education. The correct use of these technologies has improved the learning process of architecture, scale correlation and building engineering for the students.

The teaching of architecture with virtual immersion focuses on space exploration, learning in situ, the circulation of movement, lighting, the structure, etc. Architectural design is a complex cognitive process combined with the distribution of different functions and applications of materials, also it is related to models, volumetric, materials, natural and artificial lighting, structure. We aim to facilitate the learning process and release some of the cognitive load that architectural studies contain, to increase improvisation and creativity.

During our teaching experience for two semesters at the National Polytechnic School of Athens, we had the opportunity to do surveys with architectural students in the course of design. 96.5% of the architectural students we questioned agree that the profession of the architect is increasingly becoming a profession that is linked and depends on the computer. We would like to transform this in the future, into “the profession of the architect is linked and depends on the environment”.

We found that the teaching nature of the project lacks the use of interactive tools and immersive environments that allow navigation in architectural design. In addition, the students can visit virtually the design of their colleagues and develop new learning interactions. The static 3D models can be easily transformed into interactive and immersive environments. Mixed Reality interactive visual environments allow distance learning, design and graphic design training with active project representations in virtual immersion with 360^{o} view.

To recapitulate, this research tested and designed five educational models for architects, in the form of serious games applications and we examined closely the technological immersive media of Augmented Reality. Augmented Reality is a tool that demonstrates the discovery of architectural philosophy and is a passage to a knowledge of how we interact within the physical environment. In the larger continuum of the Ecosystem of Media or Ecology and Means, we describe the axis of answering fundamental questions in architectural education, as to the role of architecture on a global scale. Mixed Reality can become a system of building in the future. The coexistence of virtual and physical environments produces novel representations of three-dimensional space. It augments spatial perception and enhances learning capacity.

We have built our pedagogical experiences in design workshops and developed digital solutions for teaching assistance and learning. The five demonstrations we set up are part of a sequence of experiments between the years 2017–2021. Each demonstration is an independent digital application; in parallel, it is part of the continuum we employ to integrate mixed reality into architectural education. Our participation in several projects and the collaboration with institutions and scientific teams (the MIM team, from Cnam in the CÉDRIC laboratory, our collaboration with the University of Paris 8, and our collaboration with MAD Artistic Emergent Canter in the Netherlands) allowed us to study more closely the structure and mechanisms of gaming and digital realities, especially video games. Finally, we combined our experience in Design Studios with NTUA architectural students. We developed educational materials on the Creative Commons license concerning the subject we are dealing with.

We developed the five examples of IT solutions to support the design studio course (as executable archives) with Unity 3D software. Our digital experiences were the means implemented to answer our research question around the use of an immersive tool for learning in architecture. The applications we have developed are as follows: 1) Folie Numérique N.5, Co-learning in architecture with the use of interactive hyperlinks, 2) Behaviour Interactive Interface plug-in, 3) Visit the Unbuilt, Virtually Real, 4) Pixel People-Data Parcours, and 5) ARtect.

We developed the first three examples as part of the European project: @postasisVirtual Artistic Laboratory. The first method we used is based on the @postasis platform. It is a webinar teaching method via a real-time and multi-user 3D platform. Scientific production in this context is part of the Open Educational Resources and Creative Commons.

The last two experiments concern AR applications. The second method is based on the development of AR applications with in situ GPS coordinates. The digital tools we developed and tested during the research are different applications; however, educational models of reflection are part of a single sequence. Each demonstration is an independent digital application that is also part of the methods we employ to integrate mixed reality tools into architecture education.

The first digital application about the folie N.5 of Parc de la Villette, focuses on the physical space existing in the narrative created inside the virtual space to guide the learner to explore 3D space.

The goal of the second educational model, through the Behaviour Interactive Interface plug-in, was to raise awareness of 3D space and the digital occupation of space by virtual agents. The element of collision avoidance between humans can be transferred to the digital environment as a primitive form of the interactive behaviour of virtual actors.

In the third educational model, we assessed the effectiveness of urban design proposals and verified the implementation of buildings in the urban fabric. In addition, transforming the virtual environment into a quickly visitable and habitable environment is a way to increase students' learning capacity and self-assessment during the design activity. Finally, the hypothesis is tested via a method based on mixed reality media and the principles of architectural education. This experiment where we tested BII with architecture students was presented at the 7th eCAADe RIS 2019 symposium in Aalborg, the results of this specific study were presented in the article "Integrating Digital Reality into architectural education: Virtual Urban Environment Design and Real-Time Simulated Behaviours" (Velaora et al., 2019).

The fourth educational model introduces an emerging method of learning architecture via AR applications. Using a code (AR Location Script), we were able to link specific GPS coordinates to 3D objects and personal data that could appear on the screen. This experiment aims to explore the use of digital realities to create new emerging practices adapted to teaching architecture with augmented reality.

The last of our experimental digital developments is Application 5, named ARtect, derived from the terms Augmented Reality and Architect. The concept of this application was based on the creation of a tool familiar to the architecture student in AR. ARtect is designed to allow the realization of 3D sketches in situ. The main feature of this application is that the user can place virtual 3D objects in real-time based on the GPS coordinates of mobile smart devices (smartphone or tablet). This application to augment 3D objects in real-time was presented at the Fourth World Conference on Ieee Smart trends, in London via Zoom in 2020, on the article titled "ARtect, an augmented reality educational prototype for architectural design" (Velaora et al., 2020).

The last part of the thesis presents an analysis of the experiments we have carried out. The results of our experiments relate to:

- Levels of immersion. A virtual environment can achieve different levels of immersion (low, semi, and high-immersion) depending on the representation media used.
- The creation of interactions in virtual space can vary depending on the purpose of the application and the observations we want to obtain (e.g. geometry, volumetry, lighting, behaviours, space capacity, etc.)
- The navigation in First Person Controller offers a personalized experience and increases the immersion of the participant. The 360º view in virtual immersion presents the architectural object from different points of view.
- Remote collaboration provides new frameworks for academic exchange and enriches research. Creation on a 1:1 scale simulation especially for AR applications offers a real-time benefit regarding the difficulties that students encounter in coordinating spatial proportions.

Our methods suggest providing various educational models and research on the theme of virtual immersive environments applied to architectural design. We classified the five pedagogical models into two categories according to the media used for their development. The first webinar category (Applications 1, 2, 3) highlights inconsistencies and tests different types of virtual environments. The second category of AR (Applications 4, 5) offers a rapid reflection on the project.

The results of our analysis appear that pedagogical applications 1, 3, and 5 were characterized by students as intuitive, an asset that increases the student's motivation, positive emotions, and engagement during the experience. Applications 1, 3 and 4 can be used once the modeling process is finalized to be used in the final stages of spatial design. While Application 3 is the only educational model integrated in real practice into the curriculum so far. Lastly, Application 5 can help with design in the early stages and introduce the student to CAD commands. This application is designed as an educational tool for architectural students.

Features such as immersion, 360° view, and six degrees of freedom during the design experience also emphasize that AR can benefit architecture education more in comparison to webinar approaches. The freedom of movement of a rigid body in three-dimensional space refers to the six degrees of freedom (6DoF). Specifically, the body is free to change position forward/backward (surge), up/down (lift), left/right (swing) to navigate the virtual space in 3D. AR and VR applications can liberate the designer movement and spatial expression of the designer and involve more senses. The research community increasingly perceives the freedom of movement in the3D digital space of mixed reality media during design.

Mixed reality and digital applications help architectural students design interactions in the virtual environment based on design analysis, behaviour and constructive spatial synthesis. The navigation in the simulated architectural design highlights blind spots of the project, which are not visible by the technical drawing representing the space, as it is the architectural drawing. Surveys show that Augmented Reality is well received by students and can become a decision-making tool, a design selection tool and a tool to simulate the implementation of the architectural project on the site before construction. The architect's workspace as an environment takes on unlimited dimensions. The digital model perceived in 360^{o} can be used at the different stages of the design and construction of the project as a "preview" in real-time.

Augmented Reality cultivates spatial coherence, in parallel becomes a digital toolbox and interface for architects that permits the representation of virtually implanted objects and/or actors, in the real proportions of the site. These tools allow distancing and reflection during the adaptive and productive process of architectural reflection. There are various strategies suggested about using AR by architects. Scientists and educators in architecture assess *learning in location-based AR applications.* Our methodology uses images, GPS locations, 3D objects, and horizontal and vertical surfaces to create augmented reality experiences that facilitate architectural 3D sketching and conception.

We list some of the advantages of AR tools as we explored in our experimentations:

1. The tool increases the capabilities by reusing existing content, such as videos, images, 3D models, texts, older versions of specific items.
2. Specific cultural items can be linked with digital content of any form (video, image, text, URL, etc.)
3. Mobile devices liberate the user's movement with a wireless internet connection, supporting cultural context in several forms.
4. Offer immersive representations of objects that do not exist or will exist.
5. AR tools can restructure and reshape teaching methods, organizational structures, design orientation.
6. The tool increases the capabilities by offering a personalized experience to the user (custom).

At the beginning of this research, we found resistance, but we found adaptability and flexibility by students and tutors at the end. In addition, the integration of 3D interactive educational models increased the engagement of the students concerning the natural environment and architectural studies.

This research tested and designed educational models for architects using digital applications, and we closely examined the immersive technological media of Augmented Reality. Some of the challenges of this thesis were the coordination of such hybrid methods, and the difficulty to develop methods that benefit the students and the learning process. The applications had to be adapted to students needs and skills. We investigated the benefits and the challenges that immersive virtual environment integration is possible in formal architectural education.

The beginner architect has more and more responsibility for the learning process. Young architects use at least three to four design software from the early stages of their studies. At a European level, even global, Universities can develop methods to a) improve the conditions of study at the university through immersive virtual environments, b) promote academic integration with other disciplines, and c) develop social and cultural integration at the university. The exchange, communication and collaboration of universities are crucial to developing scientific digital tools for architects, gaining more space in the shaping of the cities.

Moreover, our methods aim to support education, learning processes and skills:

- To provide architectural students with cultural content before and during the design studio process.
- To increase learners' involvement in the learning process (by creating meaningful interactions) in sites
- To create flexibility in "what to observe."

We conclude that AR can be a powerful tool when the process gives freedom to the user by keeping the connection with the real space. Immersive and semi-immersive virtual environments can ease the transition from manual design to digital CAD design to help students understand their design strategy. The field of mixed realities and architecture is vast. We specify that our field of action was the development of educational applications for architectural design. We suggest the following teaching proposals on the integration of mixed reality media in architectural studies:

a) Educational proposal 1: Mixed reality applications and hybrid learning methods can improve the architect's perception of the 1:1 scale and thus the understanding of other architectural elements (memory—learning).
b) Educational proposal 2: Mixed reality and hybrid learning methods pose design parameters of perception and understanding of reality, also parameters about the integration of the architectural object.
c) Educational proposal 3: Mixed reality can integrate movement (movement in first-person view) as a perceptual sensor of real space in the pool of digital creation and architectural representation.
d) Educational proposal 4: Mixed reality can re-educate the designer's body since it increases engagement. It facilitates the understanding of the design by interacting with specific targets (e.g., devices like cameras, GPS locations, objects, etc.).
e) Educational proposal 5: Mixed reality makes it possible to deepen the three-dimensional representations of the city and the building.

At the end of the twentieth century, the developed technology (e.g., HoloLens, Oculus) permits imagining of new methods of learning processes, as compared to other professions, after renovating and renewing the tools of design and learning design (Dorta,1998).

Augmented Reality is a tool that demonstrates the discovery of architectural philosophy and is a passage to a knowledge of how we interact within the physical environment. New architectural forms emerge from this media ecosystem to suggest "cures" for the metropolitan and natural environment. With the assistance of Mixed Reality applications, we can assess several cognitive ruptures in architectural design, improve how we build our cities, and set the basis of multisensory and transdisciplinary approaches in Design Studio. Further dangers and limitations of such approaches are constantly examined.

However, Mixed Reality is not a cure-all for design. It is another accessible medium (non-immersive VR) that can play a complementary role in the design process by helping to overcome some of the limitations of traditional media. Certainly, with the assistance of Mixed Reality applications, we can cure several cognitive ruptures in architectural design and improve how we build our cities and set the basis of multisensory and transdisciplinary approaches in Design Studio. Further dangers and limitations of such approaches are constantly examined in several domains.

For example, a possible topic for future research can investigate the relationship between urban space and VR in smart cities. Our suggestion would question the different types of digital cities as we meet in video games. Serious and therapeutic digital games scenarios could be applied in technologically advanced urban environments with good Internet connection and speed. Smart Cities, which represent set-up environments (digitally regulated environments), are an investment that has several economical aspects, with the Internet of Things development, the AI, a city can be transformed into an object of companies' and industries' profit. The medium becomes invisible; the computer disappears but it is still there. We rarely consider by how many cameras we are surrounded, considering that each person carries at least a mobile phone with a camera. Social interactions have been affected by the excessive use of cameras.

The personal data of the inhabitants can influence behaviours in the real environment through digitally enhanced senses. For further architectural research, this panoptic aspect tends to cancel private space, provoking possibly destructive behaviours. Architects must take into consideration the need for private space, as it can be considered a privilege. While public space reflects the social terrain where the architect compromises several dynamics.

Private space is directly connected to public, social and intimate cognitive space, and impacts how we perceive reality and 3d space. Smart City platforms start forming digital urban global environments (global-cities) where there are many promises, across the digital era, many dangers and even political extensions. Finally, cognitive space affects how we interact within an educational and cultural framework, also the way we build. Moreover, suggesting that Holistic Arts can graciously be beneficial for architectural studies, digital creation and research as, this merge enables a new passage to architectural knowledge through experience, individual and collective participation.

In addition, for further research, we suggest fields like Neuroscience, image analysis and Gestalt theory that can further expand the limits of this research (see: Annex 4). More research could be conducted in a direction that combines neuroscience and architectural design. As the human nervous system combines visual and tactile information about the properties of objects, this happens with AR. ARtect provides visual content through haptic experience and physical movement in 3D space. The spatial coherence of architectural design is essential to be perceived through images in relation to the physical environment. Neuroscientists argue that the simulation of natural events and social interactions provides "ecological validity" (Bohil et al., 2011) since these virtual environments are not limited to the features needed for an architectural design experiment.

We have identified the promises and demands that such approaches impose. We described the risks, efforts, and time for implementing mixed realities in architectural education to improve design quality and performance. In the larger continuum of the Ecosystem of Digital Media, we describe the axis of answering fundamental questions in architectural education regarding the role of architecture on a global scale. Mixed Reality can become a system of building in the future. The coexistence of virtual and physical environments produces novel representations of three-dimensional space, and it augments spatial perception also enhances learning capacity.

We faced several limitations regarding the development of the digital tools, also their application to real practice. Some of our limitations were technical. The main limitation of this research is that we could not test the ARtect prototype that we developed in 2020 with the architectural students of Design Studio during the semester 2020–2021 due to the restrictions in circulation concerning the sanitary crisis Covid-19. However, that can be a challenge for future researchers in this field.

In conclusion, the subject of this thesis was a risk and, at the same time, a challenge. The risk was its experimental aspect based on technologies that are going through their first stage of evolution. The challenge was the willingness to create a teaching and training tool for the young people of our time. In its future evolution, these methods could serve the teaching not only of architecture as an artistic creation but also of other arts and even some sciences. The author of the thesis wanted to assume the risk and confront the challenge with the humility required in front of the unknown.

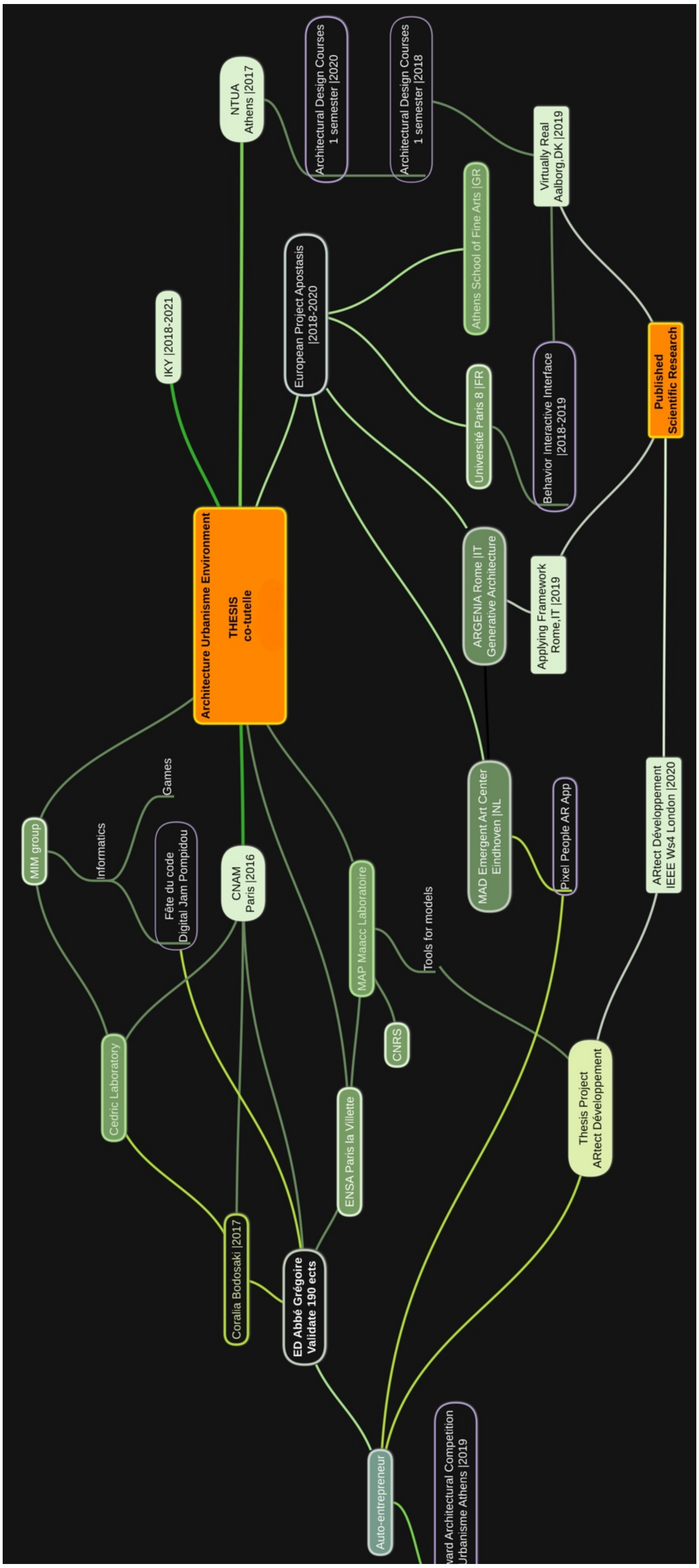


Figure 118. Map of the research - Academic ecosystem, 2017-2021.

Partial abstract in French

(Résumé Partiel)

Résumé de la thèse en français

Méthodes d'enseignement de l'architecture en immersion virtuelle

Il s'agit d'une thèse en cotutelle entre le CNAM et l'École Nationale Polytechnique d'Athènes qui a démarrée en 2016. Le contexte de cette thèse est l'enseignement de l'architecture, particulièrement l'enseignement du projet architectural avec l'assistance de média de Réalité Mixte (Réalité Virtuelle et Réalité Augmentée).

L'enseignement du projet architectural est un processus d'apprentissage particulier qui focalise sur la pratique. Le point de départ de l'apprentissage dans le studio est un problème de conception auquel les étudiants en architecture sont susceptibles d'être confrontés en tant que futurs professionnels. Pour Masdeu et Fuse (2017), il s'agit d'« *une situation professionnelle qui est reproduite dans un contexte académique* », tandis que Shulman (2005) pointe vers un type d'enseignement « *qui organise la façon dont les futurs praticiens sont formés pour leur profession* ».

Les étudiants sont censés acquérir des connaissances organisées autour de questions de conception traitées individuellement et collectivement au sein de studios de conception (Design Studio -DS). Les méthodes pédagogiques généralement utilisées dans ces studios appartiennent à la catégorie de l'apprentissage par problèmes (Problem-Based Learning). Le processus d'acquisition nécessite une pensée critique, une autoréflexion, une auto-évaluation, un apprentissage interdisciplinaire et autodirigé autour de problèmes mal définis (Schön, 2012). Dans ce contexte de formation particulier, des étudiants peuvent avoir des difficultés à acquérir certaines notions essentielles.

Le point de départ de notre thèse se base sur l'hypothèse que des outils numériques pourraient faciliter l'apprentissage de certaines notions et sur le constat que les méthodes pédagogiques n'ont que peu évolué. Au contraire d'autres disciplines, on n'observe pas de réelle transition numérique dans l'enseignement de l'architecture.

Bien que largement utilisée par les architectes dans leur activité professionnelle, la conception architecturale assistée par l'ordinateur et les logiciels de modélisation numérique 3D n'ont pas eu vraiment d'impact sur l'enseignement de la conception architecturale (Al-Matarneh & Fethi, 2017). Notamment, dans les ateliers de projets.

L'enseignement du projet s'appuie généralement sur des pédagogies traditionnelles, surtout, dans les premières années où le numérique est plutôt perçu comme un outil de représentation d'un projet conçu de manière traditionnelle. Les enseignants privilégient l'usage du dessin manuel surtout pour les phases d'idéation. Le numérique est même souvent perçu comme néfaste pour l'apprentissage de la perception de l'espace et de l'appropriation de l'échelle et des proportions spatiales. Les enseignants arguent souvent que l'utilisation intensive de logiciels de conception et d'illustration peut créer une charge cognitive qui paralyse ou retarde la créativité des apprenants. Dans la pratique professionnelle, les logiciels de CAO et de graphisme sont principalement destinés à la production des représentations conventionnelles des projets conçus de manière traditionnelle et à faciliter la communication entre les différents acteurs du secteur de la construction (architectes, ingénieurs, constructeurs, etc.). La conception en termes d'idéation n'est généralement pas faite en CAO (Dorta, 2007).

De plus, traditionnellement, les architectes conçoivent à une échelle spécifique qu'ils définissent au début de la conception. Ce processus révèle la relation et les analogies entre l'objet du design et le concepteur. Avec l'utilisation exhaustive de la CAO, l'apprenant conçoit dans un environnement infini sans échelles préétabli et dans un espace illimité. Le « zoom » répété sur l'objet de conception peut déstabiliser l'étudiant et le conduire à concevoir à une échelle souvent inconnue.

Cela suggère un besoin d'outils qui permettent aux étudiants de se promener et de visiter leurs modèles architecturaux pendant la conception afin de mieux percevoir les caractéristiques spatiales de leurs projets. Mais les outils de conception actuels, tels que la CAO et l'illustration, limitent les vues à 360° degrés dans le projet de conception architecturale. Même si les modèles de CAO offrent une précision de conception, ils réduisent parfois la perception des concepteurs (Stacey & Eckert 2003).

Conscients de ce problème, des chercheurs universitaires en France et aux États-Unis ont expérimenté avec des logiciels appelés « moteurs de jeu » (game engines), tels que Unity 3D et UnReal Engine, utilisés pour créer des jeux vidéo, des applications de Réalité Virtuelle (RA) et de Réalité Augmentée (RA) pour l'enseignement de la conception architecturale (Lescop et Chamel, 2020). La combinaison des technologies numériques comme les logiciels de CAO, de graphisme et de jeux vidéo peut rendre interactifs les modèles des architectes. L'interaction inclut la navigation virtuelle en temps réel dans la conception architecturale (immersion virtuelle).

Cette thèse peut être considérée comme une continuation de ces travaux de recherche. Notre objectif est de participer au développement de pédagogies utilisant des outils numériques et qui soient adaptées à l'apprentissage du projet notamment pendant les premières années.

« L'usage d'environnements immersifs, tels que nous les rencontrons dans les applications de RV et RA, peut-il améliorer le processus d'apprentissage de l'architecture ?» est la question principale de cette thèse.

Notre **hypothèse** est que le numérique immersif pourrait assister l'enseignement de l'architecture. L'usage des applications de réalité mixte comme la RV et la RA, pendant le studio de conception peuvent devenir un outil d'enseignement qui facilite l'éducation spatiale et la transition évolutive entre les méthodes d'enseignement traditionnelles et hybrides.

Notre **méthode** de recherche a eu pour objectif de tester différentes applications de réalités mixtes pour l'aide à l'enseignement de la conception architecturale au sein de studios de projet. Nous avons ainsi construit plusieurs modèles pédagogiques et cherché à en évaluer les possibilités et les limites.

État des connaissances dans le domaine

L'introduction d'outils immersifs lors de la conception architecturale a contribué à remodeler les modalités de développement de nouveaux modes de représentation (Dorta & Taouai, 2021). Les applications de réalité hybride fournissent des environnements immersifs qui permettent aux concepteurs de travailler seuls ou en équipe avec des croquis 3D immersifs à grande échelle (Dorta & Taouai, 2021).

L'utilisation d'environnements immersifs a montré plusieurs avantages, car ils améliorent la compréhension des proportions et des échelles et l'évaluation des propositions de conception (Beaudry-M et al. 2018, Dorta & Taouai, 2021).

Certes, des outils immersifs tels que Benchworks (Seichter, 2004), Collaborative Design Platform (Schubert et al., 2016), Luminous Planning Table (Ben-Joseph et al., 2001) sont des exemples d'usage possible de la réalité mixte dans l'atelier du projet.

En outre, il existe des plateformes hybrides et des CAVEs, comme Hyve-3D (Dorta et al., 2016), Simulation Lab (Kalisperis et al., 2002) et Coraulis (Milovanovic et al., 2017) qui sont des systèmes immersifs qui facilitent la co-conception et la création de modèles en Réalité Mixte, permettent l'interaction à l'aide d'appareils portables. Ce type d'outil numérique est conçu pour transformer la salle de Design Studio en un espace immersif.

Des recherches ont montré que des méthodes basées sur la RA (Réalité Augmentée) améliorent l'efficacité de l'apprentissage dans l'éducation en général (Oluwaranti, 2015). La recherche montre également un degré plus élevé de satisfaction grâce à la technologie de RA et à l'amélioration de l'engagement et de la motivation (Redondo et al., 2013). L'utilisation correcte de ces technologies a amélioré le processus d'apprentissage des étudiants en architecture et en génie du bâtiment (Redondo et al., 2013).

De plus, les applications de réalité augmentée aident à la conception d'espaces intérieurs (Hsu et al., 2013) et à la planification urbaine (Broschart, 2015 ; Cirulis, 2013). C'est un puissant outil de visualisation qui projette, infiltre et simule la réalité.

Pour l'enseignement de l'architecture, la RA pourrait renforcer la relation directe entre le concepteur et l'environnement physique. La réalité augmentée aide à l'enseignement de la géométrie descriptive, de l'ingénierie, de l'infographie et de la formation en conception (Voronina, 2019).

La RA et la RV semblent être des outils de visualisation robustes qui peuvent aider à l'enseignement de l'architecture. Cependant, dans l'enseignement de la conception architecturale, très peu de studios bénéficient encore de ces technologies dans la pratique réelle.

Souvent, les grands écrans (comme nous les observons dans les CAVEs) représentent les espaces plus grands qu'ils ne sont réellement conçus. En revanche, les modèles physiques en cartons sont plus petits que l'objet architectural. En d'autres termes, le numérique agrandit les dimensions architecturales, tandis que les maquettes traditionnelles compriment les dimensions architecturales.

Le défi consiste à produire des systèmes virtuels immersifs qui simulent la conception architecturale avec précision en termes de dimensions, de proportions, d'analogies et de matériaux. Les environnements virtuels immersifs pourraient favoriser la précision et la créativité. À cette fin, les architectes, les développeurs et les experts d'autres disciplines doivent travailler ensemble.

Expérimentations

Au cours de notre expérience d'enseignement de deux semestres (en 2018 et en 2020) à l'École Nationale Polytechnique d'Athènes (NTUA), dans les ateliers du projet, nous avons constaté que la pédagogie du projet manque d'une utilisation d'outils numériques avec des environnements immersifs qui permettent la navigation dans la conception architecturale.

En 2018, le studio du projet a été mené de manière traditionnelle avec des maquettes physiques. Nous avons interrogé 97 étudiants en architecture. 79,2 % des élèves ont déclaré avoir de la difficulté à comprendre l'échelle du projet et à faire des transitions entre différentes échelles (ex., 1:10, 1:200, 1:500). En 2020, le studio du projet a été mené totalement en ligne à distance à cause de la pandémie. Cette contradiction nous a permis d'effectuer quelques observations. Premièrement, nous avons observé que les étudiants sont curieux vis-à-vis des environnements immersifs (RA/RV) qui pourraient résoudre les défis de conception ou améliorer la transition de la conception manuelle à la conception numérique.

En plus, nous avons constaté que les modèles hybrides d'apprentissage mixant des approches traditionnelles et numériques pourraient permettre des nouvelles formes d'enseignement du projet.

Nous avons développé cinq exemples de solutions informatiques pour soutenir le cours de studio de conception (sous forme d'archives exécutables) avec le logiciel Unity 3D. Nos expériences numériques ont constitué les moyens mis en œuvre pour répondre à notre question de recherche autour de l'utilisation d'un outil immersif pour l'apprentissage en architecture.

Les applications que nous avons développées sont les suivantes :

1) Folie Numérique N.5, Co-learning in architecture with the use of interactive hyperlinks, 2) Behaviour Interactive Interface plug-in, 3) Visit the Unbuilt, Virtually Real, 4) Pixel People-Data Parcours, et 5) ARtect.

Nous avons développé les trois premiers exemples dans le cadre du projet européen : @postasisVirtual Artistic Laboratory. La première méthode que nous avons utilisée est basée sur @postasis plateforme. Il s'agit d'une méthode d'enseignement par webinaire via une plateforme 3D en temps réel et multi-utilisateur. La production scientifique dans ce cadre fait partie des ressources éducatives libres (Open Educational Resources and Creative Commons). Les deux dernières expérimentations concernent les applications en RA. La deuxième méthode est basée sur le développement d'applications en RA avec des coordonnées GPS in situ.

Les outils numériques que nous avons développés et testés au cours de la recherche sont des applications différentes ; cependant, les modèles éducatifs de réflexion font partie d'une seule séquence. Chaque démonstration est une application numérique indépendante qui fait également partie des méthodes que nous employons pour intégrer les outils de réalité mixte dans l'enseignement de l'architecture.

Modèle pédagogique 1 - Folie Numérique N.5, Parc de la Villette

Le titre de cours suggéré est « *Co-apprentissage en architecture avec l'utilisation d'hyperliens interactifs dans l'environnement virtuel multi-utilisateur 3D de la plateforme @postasis. L'exemple du pavillon « Folie Numérique* » à Paris en tant qu'environnement éducatif interactif virtuel. Notre contribution pédagogique développe une classe virtuelle interactive en ligne concernant le Parc de la Villette. Ce modèle éducatif présente une classe virtuelle qui est basée sur l'espace physique de la Folie N.5. La classe virtuelle simule l'espace réel du bâtiment et accueille un espace d'exposition virtuel. L'utilisateur peut naviguer dans l'espace virtuel et interagir avec des objets différents qui se sont connectés sur le web.

Les interactions dans le premier modèle pédagogique permises dans l'espace virtuel concernaient l'interaction de l'utilisateur avec des hyperliens de web pages, pendant la navigation sur une exposition virtuelle concernant des textes et des dessins du Parc de la Villette (rez-de-chaussée). Également, il s'agit de la participation virtuelle en temps réel à la conférence tenue en présentielle au deuxième étage de la Folie Numérique pendant le Troisième événement multiplier de la plateforme *@postasis.* L'application a offert la possibilité au public de participer à distance et d'accéder aux présentations PowerPoint des conférenciers.

Avec le premier modèle éducatif, nous avons initié l'apprenant au concept « du réel au virtuel », car le principe de ce cours est d'aller de l'espace réel (construit) vers l'espace virtuel (webinaire) et vice versa. L'idée que l'apprenant est simultanément présent dans le même espace virtuel et physique augmente les niveaux d'immersion. Ce concept peut être appliqué dans plusieurs espaces, tels que les musées, les bibliothèques, les espaces publics, les maisons, etc. Par conséquent, cette approche met l'accent sur l'espace physique existant dans la narration créée à l'intérieur de l'espace virtuel pour guider l'apprenant. Nous caractérisons ce modèle comme un modèle de conception qui favorise les descriptions, l'immersion imaginative et l'implication émotionnelle.

Ce premier modèle pédagogique présente un processus d'apprentissage narratif et interactif dans l'environnement virtuel interactif 3D.

Notre méthode visait à proposer une méthode pour les environnements architecturaux (organisations géométriques, navigation, interaction) qui guide l'apprenant à appréhender l'espace avec des outils multi-utilisateurs et en temps réel pour mieux faire face aux défis de conception.

La conception architecturale est un travail hautement contextuel qui équilibre les attributs de l'environnement extérieur existant. Sur la base du cadre du projet européen @postasis, l'approche du webinaire étudie davantage les attitudes des apprenants à l'égard des environnements d'apprentissage en réalité virtuelle (Huang et al., 2009).

L'environnement numérique semi-immersif de ce modèle pédagogique est informatif, explicatif, analytique et perspicace, car il fournit des représentations contextuelles riches similaires au contexte du monde réel.

Modèle pédagogique 2 - Behaviour Interactive Interface plugin

Le deuxième modèle éducatif *Behaviour Interactive Interface* (BII) est un logiciel plug-in développé pour être intégré à la plateforme @postasis (collaboration artistique à distance). En tant que membre de l'équipe scientifique de Paris 8 (Ingénieure d'Études), nous avons développé l'interface interactive Behaviour (BII). Ce plug-in offre la possibilité d'outils de population et d'habitation virtuelle. La conception d'une telle approche combine des acteurs virtuels (agents) avec l'environnement virtuel. Le plug-in BII a été présenté lors du Deuxième événement multiplicateur de @postasis à Eindhoven et plus tard lors au Troisième événement multiplicateur à Paris en 2019.

Nous avons développé un système dynamique basé sur le hasard, la complexité et le mouvement dans un environnement virtuel, permettant des interactions entre acteurs virtuels. Nous avons focalisé à l'exploration du « hasard » et du mouvement aléatoire à l'intérieur de l'environnement virtuel. L'objectif était de créer un système d'affichage dynamique permettant aux acteurs virtuels de distribuer des tâches et des attributs aux entités virtuelles.

L'objectif était de sensibiliser à l'espace 3D et à l'occupation numérique de l'espace par des agents virtuels. Le comportement humain a la tendance à choisir des passerelles en fonction de leur environnement et d'autres sujets en mouvement.

Les sujets (acteurs virtuels et physiques) ont tendance à changer la direction du mouvement, la vitesse ou l'échelle pour éviter la collision avec un autre sujet en mouvement ou un objet statique (Rymill & Dodgson, 2005). L'élément d'évitement de collision entre humains peut être transféré dans l'environnement numérique comme une forme primitive du comportement interactif des acteurs virtuels.

La catégorie de cette démonstration numérique appartient à une application autonome (« bac à sable »). L'un des principaux objectifs de ce logiciel était de fournir un système dynamique de génération de population numérique à l'intérieur d'environnements virtuels 3D, créant une généalogie hiérarchique entre les objets virtuels (objets 3D, sprites 2D).

En utilisant cette interface, l'apprenant définit les conditions de mouvement et d'interaction (« comportement ») des acteurs virtuels dans l'environnement numérique. Ce plug-in donne la possibilité d'attribuer des « comportements » à des objets virtuels dans un environnement numérique simulé en donnant des valeurs à des fonctions et en créant des conditions à l'intérieur de l'espace virtuel. En influençant le comportement de l'acteur virtuel (par distance, collision, fonction, mouvement, et temps), les agents virtuels deviennent des liens interactifs stratégiques entre le design et l'espace.

La conception comprend parfois des obstacles intentionnels pour pousser les capacités de l'apprenant vers l'exploration de l'environnement virtuel. En parallèle, l'espace architectural en tant qu'espace de jeu permet à l'utilisateur de reconnaître instantanément les schémas de navigation.

Les outils numériques peuvent répondre à plusieurs scénarios d'habitation sur des situations critiques simulées telles que les plans d'évacuation et la protection incendie.

Les principales fonctionnalités du mouvement sont basées sur le fait d'éviter la collision avec l'environnement ou de permettre la collision avec des objets ou des éléments de l'environnement virtuel. Dans les conditions de distance (proximité et collision) et de comptage du temps, les élèves « habitent » un environnement virtuel en définissant des valeurs de condition alternative.

Notre expérience avec des mouvements aléatoires et des métriques nous a amené à conclure que des environnements virtuels compliqués ou complexes (avec des obstacles) influencent l'évolution de la dynamique numérique de la population dans l'espace et le temps. Outre l'attribution différente de valeurs aux conditions, nous avons expérimenté différentes configurations d'espace 3D.

Le comportement observé des acteurs virtuels pour éviter les obstacles était similaire à celui de l'humain.

La recherche sur le plug-in peut se poursuivre dans de nombreux aspects différents qui concernent la conception architecturale et la création numérique comme il offre la possibilité de « peupler » et d'habiter les maquettes numériques des étudiants en architecture et observer des interactions avec l'espace en conception.

Ce modèle éducatif initie l'apprenant à la notion d'habiter des espaces non construits qui peuvent être des projets imaginaires, académiques d'architecture, et des espaces physiques non accessibles. Nous simulons et observons l'évolution d'une possible population virtuelle d'entités fictives. Avec cette formation en connaissances hypermédia et en support technique, nous avons combiné notre expérience avec la conception architecturale lors du travail auxiliaire dans le Master de NTUA.

Nous avons appliqué le plug-in BII à la proposition de conception d'un groupe d'étudiants en architecture, Master (5e année), 2019, NTUA (Modèle pédagogique 3).

Modèle pédagogique 3 - Visit the unbuilt, Virtually Real

Le cadre de cette expérimentation présente un exemple numérique éducatif intitulé « Visit the unbuilt ». Il est basé sur la proposition des étudiants d'architecture pendant le studio du projet. Cette expérimentation suggère de mettre en œuvre une interaction significative des acteurs virtuels avec l'interface BII (Modèle pédagogique 2) pour un environnement urbain pendant l'exercice de design. Notre expérience a été menée lors du travail d'enseignement dans le cadre du cours Architectural Design 9 de l'École Nationale Polytechnique : Urban Design sous le thème « Logement social ». Un petit groupe d'étudiants en architecture a participé à cette démonstration.

Nous avons évalué l'efficacité des propositions de design urbain et vérifié la mise en œuvre des bâtiments dans le tissu urbain. De plus, transformer l'environnement virtuel en un environnement rapidement visitable et habitable est un moyen d'augmenter la capacité d'apprentissage et l'auto-évaluation des étudiants pendant l'activité de conception. Enfin, l'hypothèse est testée via une méthode basée sur les médias de réalité mixte et les principes de l'éducation architecturale.

Pour cette étude de cas particulière, le rez-de-chaussée a été considéré comme essentiel pour les aspects de la synthèse architecturale.

Le rez-de-chaussée est défini comme « Navigation Mesh ». Il doit s'agir d'un objet continu. Les étudiants sont partiellement immergés dans leur conception par le mouvement constant du spectateur (First Person Controller). Les élèves peuvent également regarder la vue axonométrique supérieure, gauche, droite et perspective panoptique (bird's eye view) du modèle. La navigation permettait de regarder la géométrie de l'environnement sous différents angles et points de vue.

Cette expérimentation où nous avons testé BII avec des étudiants en architecture a été présentée au 7e symposium eCAADe RIS 2019 à Aalborg, les résultats de cette étude spécifique ont été présentés dans l'article « Integrating Digital Reality into architectural education : Virtual Urban Environment Design and Real-Time Simulated Behaviours » (Velaora et al., 2019).

Cette approche d'apprentissage appartient au domaine plus large des jeux sérieux puisqu'elle a pour but d'évaluer la conception architecturale à travers des interactions (population virtuelle) dans l'environnement numérique. Ce prototype est adapté à l'expérience digitale des participants lors du studio de design.

Notre expérimentation démontre un exemple où un outil évalue l'efficacité de la conception des étudiants en mesurant les adaptations de leur conception en raison de l'interaction avec l'outil. L'apprenant contrôle certains personnages ou activités au sein de l'expérience, mais l'environnement virtuel n'interagit pas directement avec l'apprenant.

BII a permis aux étudiants en architecture d'ajouter un ensemble d'actions aux agents virtuels pendant le processus de conception de la modélisation de l'espace architectural. Ces actions incluent que l'étudiant peut facilement modifier la position des acteurs virtuels en mouvement et contrôler la génération et la destruction de ces entités virtuelles. Il donne la possibilité de créer de nouveaux éléments et d'en détruire d'autres.

L'un de nos principaux objectifs pédagogiques était de proposer des modèles de pédagogie architecturale intégrant les nouveaux médias et les applications de réalité mixte. Le troisième modèle éducatif peut être considéré comme semi-immersif puisqu'il s'agit d'une application tablette autonome.

Les étudiants peuvent observer les espaces et les formes géométriques virtuellement habités par des entités fictives et arriver à différentes solutions ou conclusions sur leur proposition de design. Cependant, le processus d'intégration pédagogique est linéaire puisque l'étape de modélisation précède l'application du plug-in BII.

L’aspect visuel fourni par l’habitation virtuelle soulève des questions et des observations sur les modèles de conception liées au comportement humain et les proportions de conception. Le mouvement des contrôleurs à la première personne dans l’environnement virtuel, combiné aux intentions du concepteur et aux calculs de la machine fusionnés dans la Réalité Mixte, peut fournir des interprétations d’autres perspectives possibles.

La limitation du BII à produire des modèles spécifiques de la population numérique peut devenir un avantage lorsque différents environnements peuvent être testés dans les mêmes conditions.

Avec cette application, nous complétons la suite des expérimentations de la plateforme de webinaire tout en abordant des questions de conception telles que la géométrie, les volumes et la navigation. Ces cours sont publiés sous la licence de Creative Commons et font partie des ressources éducatives libres (OER).

Modèle pédagogique 4 - Pixel People Data Parcours

L’application numérique de RA « Pixel People » est développée pour le MAD Emergent Art Center et la Maison Intelligente à Eindhoven avec la participation du laboratoire MAP-MAACC à Paris. Cette application que nous avons développée est un type de jeu d’évasion basé sur la localisation en RA, où le terrain de jeu d’évasion est la ville elle-même.

La méthodologie envisagée aide l’apprentissage de l’architecture à travers des visites urbaines avec les atouts que les médias de réalité augmentée fournissent.

Cette application était nécessaire pour suggérer une méthode émergente sur l’apprentissage de l’architecture via les applications en RA.

À l’aide d’un code (AR Location Script), nous avons réussi à relier des coordonnées GPS spécifiques à des objets 3D pouvant apparaître à l’écran.

Cette expérience vise à explorer l’utilisation des réalités numériques pour créer de nouvelles pratiques émergentes adaptées à l’enseignement de l’architecture avec la réalité augmentée.

L’expérimentation avait pour but de sensibiliser les participants à l’utilisation des données personnelles et au piratage pendant une promenade dans la ville d’Eindhoven. L’utilisateur est connecté via l’application à plusieurs appareils externes à l’intérieur (Internet of Things), tels que des capteurs pour mesurer la pollution, des caméras et des dispositifs d’éclairage.

Au début, nous avons étudié plusieurs façons de créer une application en RA pour la ville néerlandaise. Les applications en RA peuvent être développées sur la base d'images, d'objets, de codes QR et de localisations GPS en termes de connaissances techniques. Nous avons considéré que la connexion de la RA via des emplacements GPS permettrait aux participants de réfléchir au plan de conditions plus « réalistes » concernant l'environnement physique. Nous avons développé cette application avec un intérêt de présentation d'un point de vue architectural, libérant l'utilisateur en suivant les références et en connectant l'apprenant à l'emplacement de la présence physique. C'est pourquoi nous avons choisi d'étudier les applications de RA basées sur les coordonnées GPS, afin d'étudier la manière optimale de placer le scénario de Pixel People dans l'expérience immersive pour les utilisateurs.

Le script de localisation RA a permis la création de multiples interactions entre les participants et l'environnement physique de la ville. Les participants parcourent la ville et interagissent avec elle à travers un écran tactile (tablettes).

Dans le cas de la RA, le système de coordonnées GPS de la position de l'utilisateur participe activement à l'expérience immersive. Le système de coordonnées de l'utilisateur fusionne avec le système de coordonnées de l'ordinateur et de l'environnement naturel.

Le thème « jouer la ville » est évident à travers ce jeu d'évasion du cyberespace. La ville numérique n'est pas considérée comme un simple environnement programmable (smart city), mais apporte dans le dialogue des médias de Réalité Mixte et les caractéristiques topologiques du lieu. Cette approche relie le concepteur aux facteurs réels de ses propositions de conception. En plus d'être un puissant outil de représentation, la RA peut orienter les étudiants pour naviguer dans l'environnement urbain en fonction de points d'intérêt spécifiques (situated learning). L'observation et la mémorisation des parties de l'environnement physique bénéficient la réflexion architecturale et donc la conception spatiale et l'apprentissage de l'architecture.

À l'intérieur du cursus d'un semestre, pour une éventuelle appropriation académique de cette approche, le rôle de l'enseignant est de préparer une promenade en RA sur le site de la mise en œuvre du projet avant le début de l'exercice. Le défi de l'enseignant est de valoriser la fonctionnalité de prise de décision de cette méthode (comparer, apprécier, en apprendre davantage sur les emplacements), car le tuteur identifie une façon intuitive de percevoir, de naviguer et de concevoir la ville.

Les médias de réalité mixte peuvent modifier la conception architecturale, et le design reste un sujet de recherche supplémentaire auquel nous avons essayé d'accéder dans l'application 5.

Modèle pédagogique 5 – ARtect

Le dernier de nos développements numériques expérimentaux est l'Application 5, nommé ARtect, dérive des termes Réalité Augmentée et Architecte. Le concept de cette application était basé sur la création d'un outil familier à l'étudiant en architecture.

ARtect est une application de RA numérique pour les architectes, les designers, les chercheurs et les artistes. ARtect est conçu pour permettre la réalisation des croquis 3D in situ. La principale caractéristique de cette application est que l'utilisateur peut placer des objets 3D virtuels en temps réel en fonction des coordonnées GPS des appareils intelligents mobiles (smartphone ou tablette). L'outil offre la possibilité de visualiser des modèles 3D en RA dans un environnement extérieur et intérieur.

Nous avons observé que les outils traditionnels pour les architectes tels que les dessins et les modèles offrent une expérience limitée en ce qui concerne la perception sensorielle de l'espace et la conception architecturale lors des études en architecture. La création d'une scène de RA en plaçant plusieurs modèles 3D et graphiques 2D en temps réel, via une bibliothèque personnalisée, sur des lieux géographiques pourrait assister l'apprentissage de la conception du projet. L'application pédagogique pour l'enseignement de l'architecture offre :

8. La manipulation d'objets virtuels sur trois axes (x, y, z).
9. Une expérience immersive.
10. Un outil de mesure en RA qui permet de calculer les distances en traçant une ligne sur la scène virtuelle.
11. La barre d'outils (toolbar) qui est basée sur des commandes de CAO.

Cette application pour augmenter des objets 3D en temps réel a été présentée à Forth World Conférence on Smart trends IEEE, à Londres via Zoom en 2020, sur l'article au titre *« ARtect, an augmented reality educational prototype for architectural design »* (Velaora et al., 2020).

Ce prototype d'application numérique visait à recréer les commandes de conception de base fournie par la CAO en réalité augmentée, telles que sélectionner, copier, copier plusieurs copies, déplacer, faire pivoter, mettre à l'échelle, mesurer la distance et supprimer un objet. Ces commandes donnent la possibilité à l'utilisateur de créer des croquis volumétriques en temps réel dans des emplacements géographiques.

En outre, ARtect est un outil de dimensionnement pour vérifier l'échelle des objets importés ; nous affirmons que c'est le modèle qui aide le plus à comprendre l'échelle et les proportions de l'espace 3D.

L'innovation de ce prototype de RA est que les apprenants peuvent sauvegarder et télécharger leurs croquis 3D sous forme de scènes virtuelles sur leurs ordinateurs pour continuer à modifier leurs modèles avec des outils de CAO traditionnels.

Ce prototype augmente les objets 3D en temps réel sur la base d'un système de coordonnées de positionnement géographique (GPS) collecté par les appareils mobiles. Elle est conçue pour fonctionner à la fois à l'extérieur et à l'intérieur.

Dans le mode par défaut de l'application 5, l'apprenant peut remplir l'espace avec des cubes de 1 m (sous forme de contenu virtuellement augmenté). Les fonctionnalités de l'application permettent à l'utilisateur de naviguer simultanément dans l'espace virtuel et réel, immergeant le concepteur dans ses décisions réelles.

Le processus d'apprentissage peut être décrit comme à la fois productif et communicatif puisque l'expérience de l'espace à 360^{o} degrés de vision peut aider les apprenants à communiquer leurs intentions et leurs objectifs. L'interface permet une modification instantanée de l'environnement virtuel, augmentant ainsi la productivité, car elle offre plusieurs vues sous différents angles. Cette méthode vise à faciliter les étudiants qui font face à des difficultés dans la compréhension de l'échelle, les détails et le zoom avant et pendant la conception architecturale.

En tant que processus d'apprentissage, il est conçu pour diriger l'apprenant vers l'environnement physique ou le site de mise en œuvre. Il inspire une approche réaliste des proportions et de l'échelle des bâtiments autour. Nous constatons qu'un tel environnement immersif peut devenir un processus automatisé lorsqu'il est appliqué dans le Design Studio à l'avenir. Les étudiants utilisant des appareils portables n'ont pas besoin d'apprendre à coder ou d'avoir d'autres tâches en tête que la conception et la synthèse volumétrique puisque l'application fonctionne également en mode autonome quand offline (persistante).

Nous avons développé ce prototype de réalité augmentée basé sur la localisation GPS comme portail vers l'expérience immersive. Notre objectif reste de donner de la liberté à l'apprenant, en termes de conception, sans augmenter sa charge cognitive pour apprendre des logiciels supplémentaires.

L’étudiant en architecture est déjà submergé par la quantité de connaissances à absorber, telles que les compétences en conception manuelle, les compétences en conception de logiciels (CAO), la production de modèles physiques, l’histoire et la théorie. Cette méthode peut être individualisée et en groupe et est abordable pour les étudiants, car nous apprécions les outils que nous utilisons dans la vie quotidienne, telle que les téléphones mobiles.

Les scénarios de conception qui doivent être exclus peuvent être d’abord testés virtuellement dans des modèles non physiques à l’échelle (maquettes). Le prototype numérique est conçu comme une boîte à outils pour les architectes et vise à faciliter la transition de conception manuelle et numérique. Il permet la distanciation et la réflexion sur son modèle sans forcer une précision de conception absolue depuis le début de la conception ; il peut devenir un outil de synthèse spatiale et de prise de décision pour les premières étapes de la conception.

À l’avenir, d’autres fonctionnalités telles que des lignes fluides, des géométries, des subdivisions et des matériaux pourront être ajoutées à cette application ou à des applications RA similaires. La difficulté pour les architectes est de communiquer avec les développeurs, et vice versa pour ce type de conception intégrée de techniques mixtes.

Les défis de développement de ce prototype étaient variés. Plus précisément, la pièce fournit un environnement virtuel pour modifier des objets 3D dans les trois axes (x, y, z). Le principal problème était de sélectionner un objet 3D dans un écran 2D qui pouvait être déplacé en profondeur. De plus, la configuration d’une grille de sol stable pour ancrer des objets 3D a éliminé les contraintes concernant la précision de l’augmentation afin d’améliorer le flux et les performances de l’expérience d’apprentissage immersive.

De plus, depuis le début du développement de cet outil en 2020, nous n’avons pas pu effectuer de tests supplémentaires avec les étudiants en raison de restrictions en dehors du domaine de l’éducation (crise sanitaire mondiale). L’année académique 2020–2021 a été caractérisée par l’enseignement à distance et les limitations de la circulation (confinement). Nous avons expérimenté l’outil avec seulement de plus petits groupes indépendants. Par conséquent, en termes d’intégration de cette approche dans le programme académique de conception architecturale, notre enquête a été limitée. Cependant, nous considérons que cette dernière expérimentation a le plus à offrir dans le processus d’apprentissage du studio de design.

Analyse des expérimentations

La dernière partie de la thèse présente une analyse des expérimentations que nous avons effectué. Le bilan de nos expérimentations porte sur :

- L'immersion

  Un environnement virtuel peut obtenir différents niveaux d'immersion (basse, semi et haute-immersion) selon les médias de représentation employés.

- La création d'interactions dans l'espace virtuel, peut varie selon le but de l'application et les observations que nous voulons obtenir (ex. géométrie, volumétrie, éclairage, comportements, capacité d'espace, etc.)
- La navigation en First Person Controller, offre une expérience personnalisée et augmente l'immersion du participant. La vue 360° dégrée en immersion virtuelle présente l'objet architectural de différents points de vue.
- La collaboration à distance fournit nouveaux cadres d'échange académique et enrichit la recherche et la création.
- La simulation à l'échelle 1:1 surtout aux applications de la RA offre un bénéfice en temps réel concernant les difficultés que les étudiants rencontrent concertant les proportions spatiales.

Nos méthodes suggèrent de fournir divers modèles éducatifs et la recherche sur le thème des environnements immersifs virtuels appliqués à la conception architecturale.

Nous avons classé les cinq modèles pédagogiques en deux catégories en fonction des médias utilisés pour leur développement. La première catégorie webinaire met en évidence des incohérences, et test des différents types d'environnements virtuels. La deuxième catégorie de RA offre une réflexion rapide sur le projet. Il semble que les modèles pédagogiques 1, 3 et 5 aient été caractérisés par les étudiants comme intuitifs, un atout qui augmente la motivation, les émotions positives et l'engagement de l'élève pendant l'expérience. Les modèles 1, 3 et 4 peuvent être utilisés une fois que le processus de modélisation est finalisé pour servir aux dernières étapes de la conception spatiale. Au contraire, le modèle 5 peut aider à la conception dans les premiers stades et initier l'étudiant aux commandes de CAO. Le modèle 3 est le seul modèle intégré dans le programme d'études jusqu'à présent. Les caractéristiques telles que l'immersion, la vue à 360° et six degrés de liberté pendant l'expérience de conception soulignent également que la RA peut bénéficier l'enseignement de l'architecture plus en comparaison avec les approches webinaires.

Conclusion

Nous concluons que la RA peut être un outil puissant lorsque le processus donne de la liberté à l'utilisateur en gardant la connexion avec l'espace réel. Les environnements virtuels immersifs ou semi-immersifs peuvent faciliter la transition de la conception manuelle vers la conception CAO numérique pour aider les étudiants à comprendre leur stratégie de conception.

Le domaine des réalités mixtes et de l'architecture est vaste. Nous précisons que notre champ d'action était le développent des applications éducatives pour les étudiants en architecture. Nous suggérons les propositions d'enseignement suivantes sur l'intégration des médias de réalité mixte dans les études architecturales :

- Proposition d'enseignement 1 : Les applications de réalité mixte peuvent améliorer la perception de l'architecte de l'échelle 1:1 et donc la compréhension d'autres éléments architecturaux (mémoire – apprentissage).
- Proposition d'enseignement 2 : La réalité mixte pose des paramètres de perception et de compréhension de la réalité et d'intégration de l'objet architectural.
- Proposition pédagogique 3 : La réalité mixte peut intégrer le mouvement (mouvement en vue à la première personne) comme capteur perceptif de l'espace réel dans le pool de la création numérique et de la représentation architecturale.
- Proposition pédagogique 4 : La réalité mixte peut rééduquer le corps du designer, car elle facilite la compréhension et la conception de l'espace.
- Proposition pédagogique 5 : La réalité mixte permet d'approfondir les représentations tridimensionnelles de la ville et du bâtiment.

Notre hypothèse qui consistait à mettre en place des expériences d'apprentissage avec des environnements immersifs ou semi-immersifs pour les étudiants en architecture a été validée. Nous avons identifié un manque d'outils de RA pour le studio de conception, et nous avons donc prototypé un exemple pour les recherches futures.

Nous avons été confrontés à plusieurs limitations concernant le développement des outils numériques, ainsi que leur application à la pratique réelle. Certaines de nos limites étaient techniques. La principale limite de cette recherche est que nous n'avons pas pu tester le prototype ARtect que nous avons développé en raison des restrictions en circulation concernant la crise sanitaire. Cependant, cela peut être un défi pour les futurs chercheurs dans ce domaine.

L’enseignement tend à intégrer des approches de réalité mixte où les projets architecturaux traditionnels coexistent avec des méthodes orientées vers la conception informatique.

Cette recherche ne compare pas le dessin manuel et le numérique comme deux pratiques opposées. Nous reconnaissons dans le dessin manuel un outil irremplaçable d’idéation pour esquisser les intentions du projet. Nous reconnaissons ses potentiels mais aussi ses limites en termes d’apprentissage. En parallèle, nous affirmons que les approches traditionnelles et numériques de Réalité Mixte peuvent se compléter dans le processus d’apprentissage de la conception architecturale.

En effet, le @postasis laboratoire artistique virtuel peut devenir un terrain de découverte et d’exploration pour les conceptions architecturales. La navigation facile dans les projets des étudiants peut fournir des commentaires perspicaces pour le processus éducatif. L’apprentissage est considéré comme un processus de réflexion interactif une fois que les conditions sont définies comme adaptatives et interactives après la population numérique. D’autre part, les environnements immersifs, en particulier de la réalité augmentée, comprennent des aspects de la ville (rues, coordonnées, bâtiments, façades) qui peuvent aider les étudiants à identifier directement les éléments architecturaux à l’échelle humaine. De plus en plus d’appareils portables prennent en charge les caméras RA. Les grandes entreprises de CAO telles qu’Autodesk et Graphisoft pourraient bientôt adopter des approches multimédias de réalité mixte de la RA à l’avenir.

Nous affirmons, d’autre part, que les enseignants devraient être suffisamment préparés sur le plan pédagogique pour intégrer des environnements virtuels immersifs pendant le processus d’apprentissage.

Enfin, davantage de recherches pourraient être menées dans une direction qui combine les neurosciences et la conception architecturale. Comme le système nerveux humain combine des informations visuelles et tactiles sur les propriétés des objets, cela se produit avec la RA. ARtect fournit un contenu visuel grâce à l’expérience haptique et au mouvement sur écran dans l’espace 3D. La cohérence spatiale de la conception architecturale est essentielle pour être perçue par rapport à l’environnement physique. Les neuroscientifiques affirment que la simulation d’événements naturels et d’interactions sociales fournit une « validité écologique » (Bohil et al., 2011) puisque ces environnements virtuels ne se limitent pas aux seules caractéristiques nécessaires à une expérience de conception architecturale.

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Annexes

Annex 1 (a) - Questionnaire for research in Architecture 2018-2019

PhD Research

*Obligatoire

1. Adresse e-mail *

____

2. Which age group do you belong to? *

Une seule réponse possible.

- ( ) 18-25
- ( ) 26-35
- ( ) 36-45
- ( ) 46-55
- ( ) 56-65
- ( ) 66 and above

3. What is your gender?

Une seule réponse possible.

- ( ) Female
- ( ) Male
- ( ) Autre : ______________________

4. In which country do you live?

____

5. If any, in which field is/was your studies ?

____

6. Activity *

Une seule réponse possible.

- ( ) Entrepreneur
- ( ) Employee
- ( ) Teacher
- ( ) Student
- ( ) Autre : ______________________

Internet

7. How often to you use the internet in your daily life? *

Une seule réponse possible.

- ( ) Everyday
- ( ) 1-3 times a week
- ( ) 1-3 times a month
- ( ) Rarely
- ( ) Not at all

8. How often do you use the internet at/for work? *

Une seule réponse possible.

- ( ) Everyday
- ( ) 1-3 times a week
- ( ) 1-3 times a month
- ( ) 1-3 times a year
- ( ) Not at all

9. What is your relationship with digital devices (cellphone, computer, communication systems)? *

Une seule réponse possible.

- ( ) Very good
- ( ) Good
- ( ) Mediocre
- ( ) Indifferent
- ( ) None

10. Which of the following devices, if any, do you own and use regularly? *

Plusieurs réponses possibles.

- [ ] Smart phone
- [ ] Tablet
- [ ] Laptop
- [ ] PC/iMac
- [ ] Games console
- [ ] Wearable technology (smart watch etc.)
- [ ] Smart TV
- [ ] None of the above

Autre : [ ] ______________________

11. How often do you use applications on your mobile phone to play? *

Une seule réponse possible.

- ( ) Everyday
- ( ) 1-3 times a week
- ( ) 1-3 times a month
- ( ) 1-3 times a year
- ( ) Not at all

12. How often do you use applications on your mobile phone to communicate (viber, what's up, messenger, snapchat, etc.)? *

Une seule réponse possible.

- Everyday
- 1-3 times a week
- 1-3 times a month
- 1-3 times a year
- Not at all

13. How frequently do you access social media platforms (facebook, instagram, linkedin, twitter, etc.) ? *

Une seule réponse possible.

- Everyday
- 1-3 times a week
- 1-3 times a month
- 1-3 times a year
- Not at all

Cinema

14. How is your relationship with cinema? *

Une seule réponse possible.

- Very good
- Good
- Mediocre
- Indifferent
- None

15. How often do you watch films? *

Une seule réponse possible.

- Every day
- 1-3 times a week
- 1-3 times a month
- 1-3 times a year
- Not at all

16. Which movie genre do you prefer? *

Une seule réponse possible.

- Action
- Adventure
- Documentary
- Strategy
- Imagination
- Science Fiction
- Thriller
- Other (comedy, romantic comedy, musical, κτλ.)

17. Choose your preferred movie environment (scenography). *

Une seule réponse possible.

- Abstarct
- Simulation
- Strategy
- Natural
- Urban
- Imaginery
- Realistic
- Other

18. Which element of the cinematic environment has influenced more your choice? *

Une seule réponse possible.

- Sound
- Movement
- Landscape
- Action
- Colour
- Scenario
- None
- Άλλο

Video games

19. How is your relationship with video games? *

Une seule réponse possible.

- Very good
- Good
- Mediocre
- Indifferent
- None

20. I prefer to play video games on... *

Une seule réponse possible.

- concole
- pc
- mobile phone
- laptop
- I don't play/watch video games
- Autre : ______________________

21. How often do you play video games? *

Une seule réponse possible.

- Everyday
- 1-3 times a week
- 1-3 times a month
- 1-3 times a year
- Not at all

22. Mark the game environment of your preference. *

Une seule réponse possible.

- Mmorpg (massively multiplayer online role-playing game)
- Action/Adventure
- Simulation
- Education / training
- Serious Games
- Puzzle
- Arcade
- TV Reality
- Sandbox games
- I don't play / watch video games

23. Which type of game do you prefer? *

Une seule réponse possible.

- Action
- Adventure
- Simulation
- Strategy
- Puzzle
- Creation
- I don't play / watch video games

24. Which element of the digital/virtual environment of the game has influenced more your choice? *

Une seule réponse possible.

- Sound
- Movement
- Landscape
- Action
- Colour
- Scenario
- Intreraction
- None

25. In a video game I prefer to... *

Une seule réponse possible.

- provoke
- participate
- observe
- do training
- communicate
- entertain
- relax
- I don't play/watch video games

26. Do you prefer a game that you have to pursue a goal? *

Une seule réponse possible.

- Much
- Sufficiently
- A bit
- Rarely
- Not at all
- I don't know
- I don't play/watch video games

Technology

27. I feel familiar with technology. *

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Not at all											A lot

28. What transport mean do you use daily? *

Une seule réponse possible.

- I walk (hitch-hiking)
- Car
- Bus
- Metro
- Moto
- Taxi
- Bicycle
- Other

29. Which means of transport do you use for your travels? *

Une seule réponse possible.

- I walk (hitch-hiking)
- Car
- Bus
- Metro
- Moto
- Taxi
- Car pool
- Aeroplane
- Ship / Boat
- Bicycle
- I dont't travel

30. Please indicate how much do you agree with the following statement "Technology can change the perception we have for the world". *

Une seule réponse possible.

	1	2	3	4	5	
Disagree	☐	☐	☐	☐	☐	Agree

Virtual Reality

31. Did you ever have an experience that changed your perception of reality? *

Une seule réponse possible.

☐ Yes
☐ No

32. Did you ever have an experience to visit a place that changed your perception of reality (planetarium, temple, square, etc.)? *

Une seule réponse possible.

☐ Yes
☐ No

33. Have you ever heard the term extended or mixed reality *

Une seule réponse possible.

☐ Yes
☐ No

34. Do you believe that Virtual Reality (VR) and Augmented Reality (AR) are sectors relevant to architecture ? *

Une seule réponse possible.

- Yes
- No
- I don't know

35. Have you ever heard of VR applications in one of those domains? *

Plusieurs réponses possibles.

- [ ] Medicine
- [ ] Engineering
- [ ] Technology of Space
- [ ] Cinema

Autre : [ ] ____________________

36. What, if any, of these Virtual Reality devices have you heard of? *

Plusieurs réponses possibles.

- [ ] Oculus Rift
- [ ] Google Cardboard (or other 'cardboard' devices)
- [ ] Microsoft Hololens
- [ ] Samsung Gear VR
- [ ] HTC Vive
- [ ] Playstation VR
- [ ] All of the above
- [ ] None of the above

Autre : [ ] ____________________

37. How did you hear of the above device(s) if you have heard of any? *

Plusieurs réponses possibles.

- [ ] TV Advertising
- [ ] Newspaper
- [ ] Magazine
- [ ] Poster
- [ ] Exposition
- [ ] Word of mouth
- [ ] News report
- [ ] Social Media
- [ ] University
- [ ] I don't know
- [ ] I haven't not been informed

Autre : [ ] ______________________

38. Have you ever participated in any virtual reality experiences using VR headset (Oculus Rift, Vive, Card Board, etc.)? *

Une seule réponse possible.

- ( ) Many times
- ( ) 2-3 times
- ( ) Once
- ( ) Never

39. Did you feel any danger, anxiety or fear during the experience (eg. vertigo, vomiting, etc.)? *

Une seule réponse possible.

- ( ) Very much
- ( ) Some
- ( ) Sufficiently
- ( ) A bit
- ( ) Not at all
- ( ) I haven't participated

40. What I like in VR is... *

Une seule réponse possible.

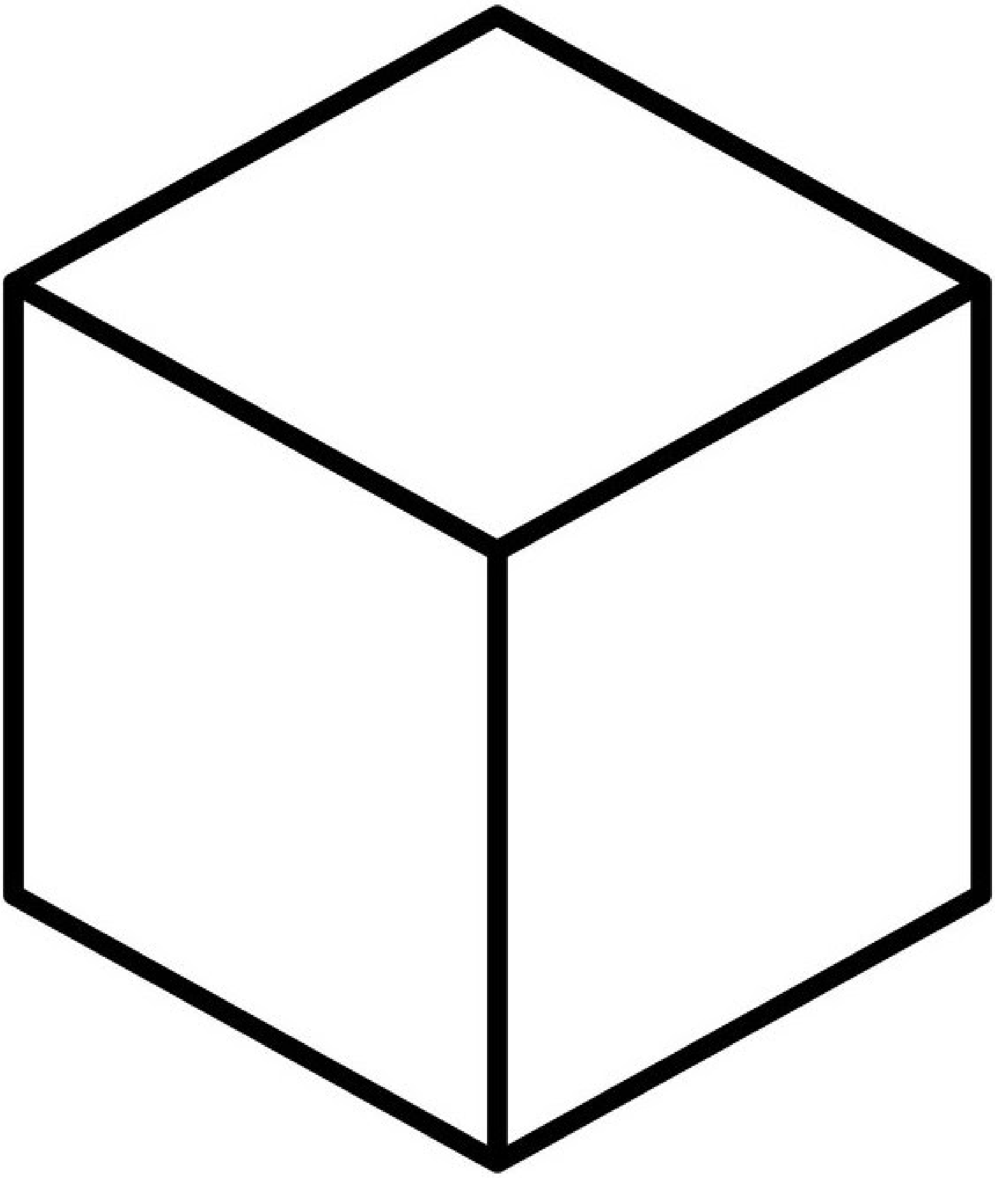
- The philosophy behind what is “real”
- The practical application
- The artistic creation
- All of the above
- I’m hesitant
- I don’t like VR

41. I think VR is... *

Une seule réponse possible.

- Just another trend
- A possible technological breakthrough
- I don’t know
- Autre : ____________________

42. What do you see in the picture below? *



Une seule réponse possible.

- A cube
- A system
- A 2D shape
- A hexagon
- 3 rhombuses
- A symbol

43. Do you think that image representations can enhance perception? *

Une seule réponse possible.

- Yes
- No
- I don't know

44. According to you, which artwork of avant-garde artist Kazimir Malevich (1879 - 1935) may be called "arkhitektons"? *

Une seule réponse possible.

- Option 1
- Option 2

45. Which color is more apparent to you in this image ? *

Une seule réponse possible.

- Green
- Red
- Grey
- White

46. Do you think that VR/AR can help you enhance your perception ? *

Une seule réponse possible.

- Yes
- No
- I don't know

47. What is your opinion on VR? *

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Negative	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Positive

Architecture

48. Are you an Architect...? *

Une seule réponse possible.

- ◯ Student
- ◯ Profesional
- ◯ Educator
- ◯ Other
- ◯ I am not an architect.

49. During my studies in architecture I had to learn at least one designing software before my degree. *

Une seule réponse possible.

- ◯ Yes
- ◯ No
- ◯ I didn't have studies concerning any design or artistic field.

50. If any, mark the software/s that you use for your projects. *

Plusieurs réponses possibles.

- [ ] Autocad
- [ ] Archicad
- [ ] Grasshopper
- [ ] Rhino
- [ ] 3ds Max
- [ ] Blender
- [ ] Adobe Suite {Photoshop, Indesign, Illustrator}
- [ ] Sketch Up
- [ ] Vectorworks
- [ ] Revit
- [ ] ArchGIS
- [ ] Unity 3D

Autre : [ ] ______________________

51. How often do you use software on your personal computer to design? *

Une seule réponse possible.

- ( ) Everyday
- ( ) 1-3 times a week
- ( ) 1-3 times a month
- ( ) 1-3 times a year
- ( ) Not at all

52. Do you use any Open Source design software for your educational/professional projects? *

Une seule réponse possible.

- ( ) Yes
- ( ) No
- ( ) I don't know

53. Architects’ profession is related to the use of computer more and more. *

Une seule réponse possible.

- Strongly Agree
- Agree
- Indifferent
- Disagree
- Strongly Disagree

54. Did you have difficulties in representing your ideas of space (ex. sketches, etc.) during the conception of your architectural/artistic project? *

Une seule réponse possible.

1	2	3	4	5

55. According to you, the most important tools of the architect nowadays are the ... *

Une seule réponse possible.

- Pencil and paper
- Laptop and printer
- Camera and projector
- Autre : ____________________

56. When I start thinking about my project, initially I look for ... *

Une seule réponse possible.

- Model and materials
- Forms and shapes
- Grid and axes
- Autre : ____________________

57. The most important thing in architectural conception is... *

Une seule réponse possible.

- Form
- Function
- Materials
- Sustainability
- Pleasure
- All of the above
- None of the above
- Autre : ____________________

58. Have you ever heard about BIM (Building Information Modeling)? *

Une seule réponse possible.

- Yes
- No

59. During an architectural project, I prefer ... *

Une seule réponse possible.

- Doing the physical model (maquette)
- Do the drawings
- Help in the presentation part
- Do sketches / perspectives that initiate the idea (concept)
- Make the 3d
- All of the above

60. It is easier for me to start my project with a sketch of a ... *

Une seule réponse possible.

- Plan
- Section
- Façade
- Axonometric
- Perspective
- Other (depends)
- I don't know
- Autre : ____________________

61. According to you, do the architectural drawings imitate reality? *

Une seule réponse possible.

- Yes
- No

62. According to you, do the architectural drawings simulate reality? *

Une seule réponse possible.

- Yes
- No

63. When I work on my project, I prefer working ... *

Une seule réponse possible.

- Alone
- With a small team (2- 4 members)
- With a larger team (7-10 members)
- Other

64. When I finish my studies in architecture, my goal is to build my own brand. *

Une seule réponse possible.

- Yes
- No
- I don't know

65. According to you, is architecture synonymous to "building"? *

Une seule réponse possible.

	1	2	3	4	5	
I don't agree						I agree

66. Usually I get my inspiration from ... *

Une seule réponse possible.

- ( ) The daily life
- ( ) Technology
- ( ) Nature
- ( ) The city
- ( ) Art
- ( ) Autre : ____________________

67. During the conception of my artistic/architectural project, I had difficulties sometimes to conceive the space in the different architectural scales (1:2000, 1:500, etc.) and make the transition between? *

Une seule réponse possible.

- ( ) Yes
- ( ) No

68. Have you ever wondered why architects do not use other hybrid scales, like 1:750 or 1:250 for the conception of their idea? *

Une seule réponse possible.

- ( ) Yes
- ( ) No

69. According to you, "spaces in transition are..."

Une seule réponse possible.

- the breathing space in between two other
- Gentle transition of quality scale (ex. from private to public)
- Gardens
- Stations
- Limits
- All of the above
- None of the above
- I don't know
- Autre : ______________________

70. I perceive reality better through... *

Une seule réponse possible.

- Dimensions
- Mesure
- Material
- Geometry
- Size
- Proportion
- Symmetry
- I don't know
- Autre : ______________________

71. I perceive reality better through... *

Une seule réponse possible.

- taste
- touch
- hearing
- eye contact
- smell
- emotions
- I don't know
- Autre : ______________________

72. Do you think that virtual reality can help architects to simulate better their conceptions in 1:1 scale representations? *

Une seule réponse possible.

- Yes
- No

73. I would like to have VR courses during my studies in the architecture school. *

Une seule réponse possible.

- Yes
- No
- I don't know

74. Do VR applications give architects the possibility to cooperate better with other disciplines? *

Une seule réponse possible.

	1	2	3	4	5	
Disagree	⬭	⬭	⬭	⬭	⬭	Agree

Evaluation of the questionnaire

75. Do you feel that the answers given in this questionnaire correspond with questions implied the use of technology during your professional life experience? *

Une seule réponse possible.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	A lot

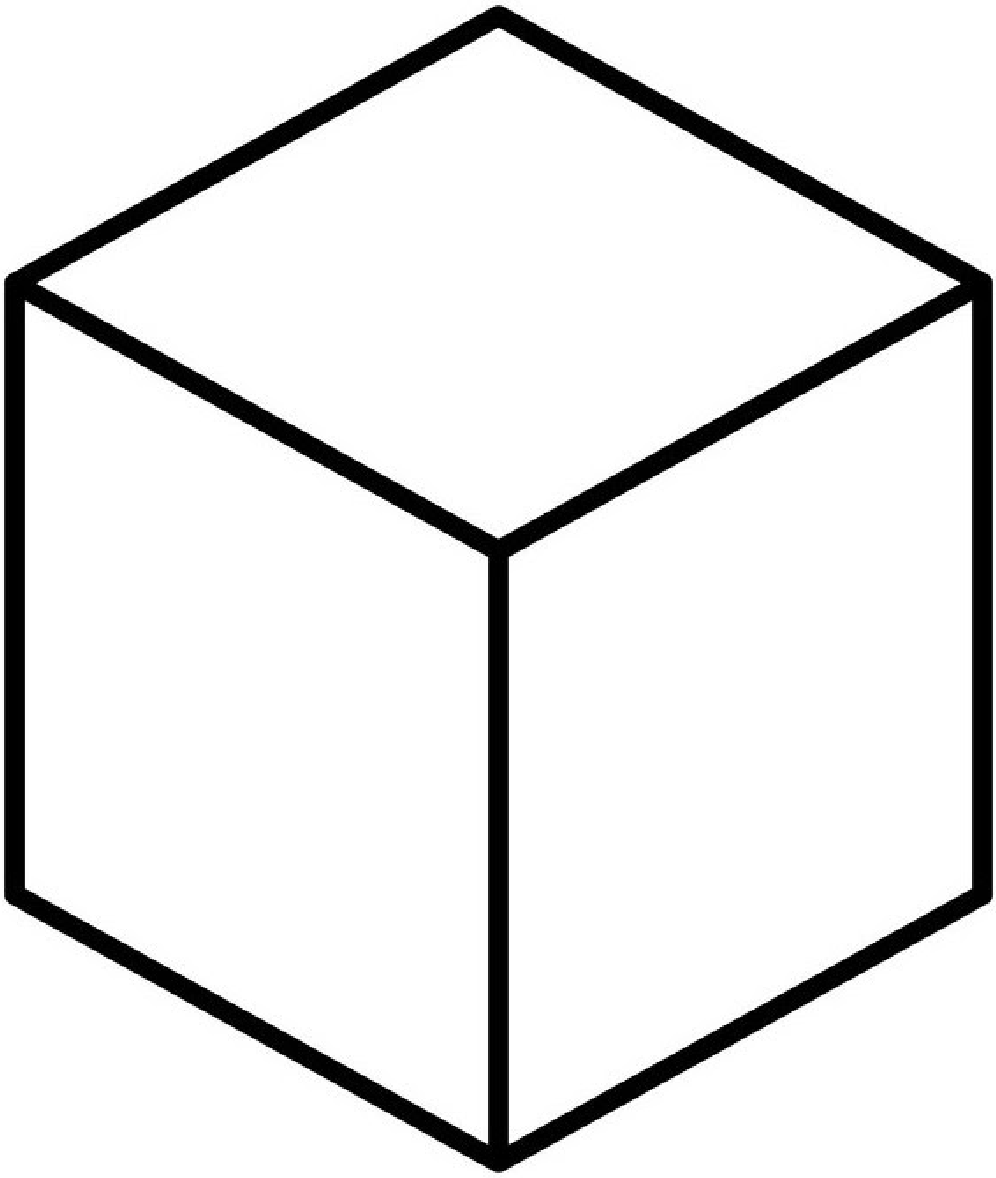
Annex 1(b) - Questionnaire Experiment 3 - for Participants

PhD research

1. In the image below, i see : 1 point

Une seule réponse possible.

- a cube
- a network
- a hexagon
- 3 rhombes
- a 2D drawing
- a symbol



2. 3D modelling is a good tool for conceiving space.

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Not at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	A lot

3. I prefer to start my architectural design from: 1 point

Une seule réponse possible.

- a plan
- a diagram
- a 2D drawing
- a 3D model
- a maquette

4. I prefer to start my conception of space : 1 point

Une seule réponse possible.

- with a hand-drawing
- with a software

5. During the course of Architectural Design 9, I had difficulties in understanding the transition into the different scales (from 1:2000 to 1:100). 1 point

Une seule réponse possible.

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

6. I would like to have a digital immersive tool for my studies. 1 point

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Not at all											A lot

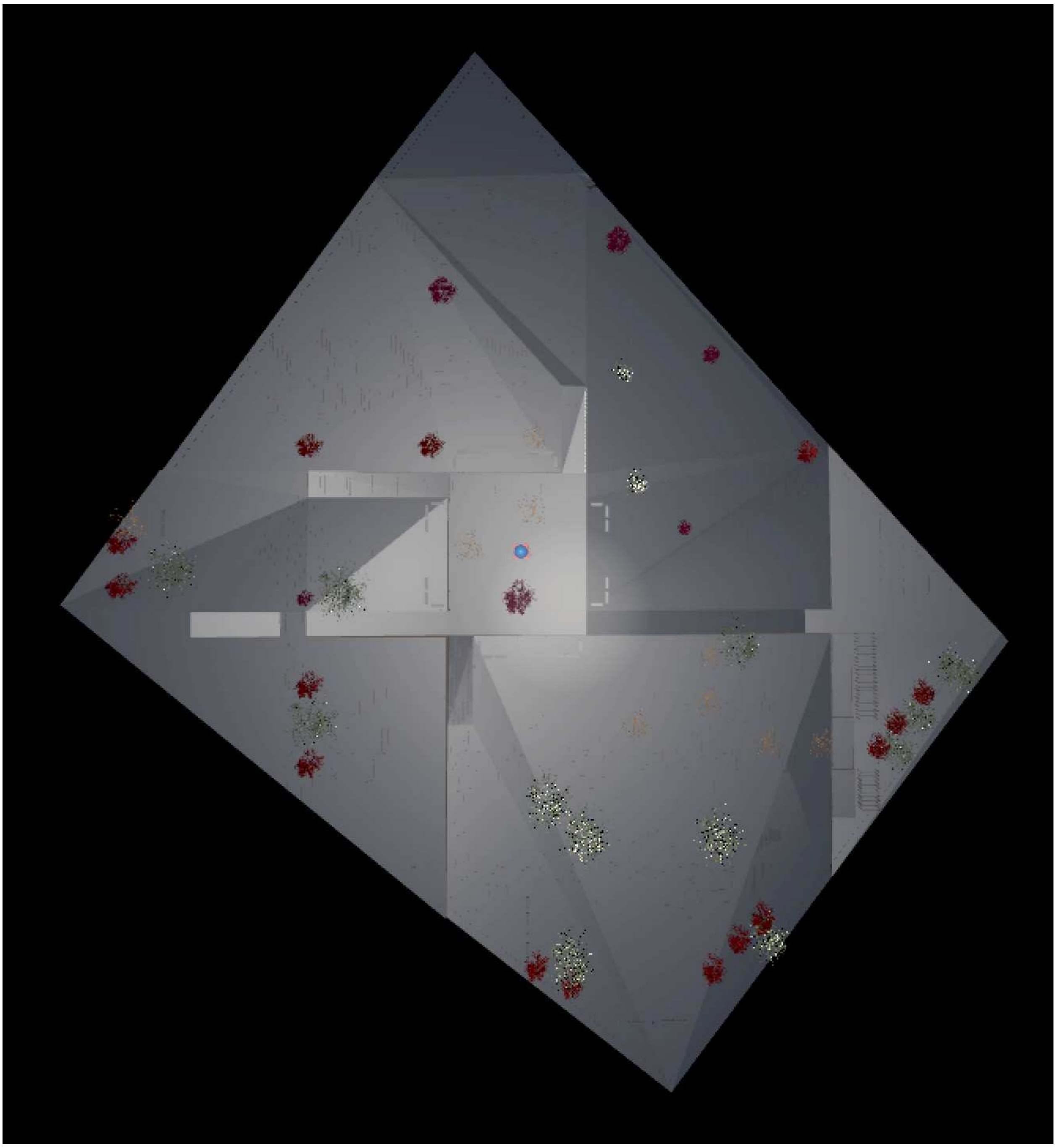
7. According to you, immersive applications can simulate best environnemental factors that architects take under consideration.

1 point

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10
	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

Landscape and Trees in the urban environnement



8. Architects define behaviours in the urban environnement. 1 point

Une seule réponse possible.

	1	2	3	4	5	
In an abstract way	◯	◯	◯	◯	◯	Absolutely

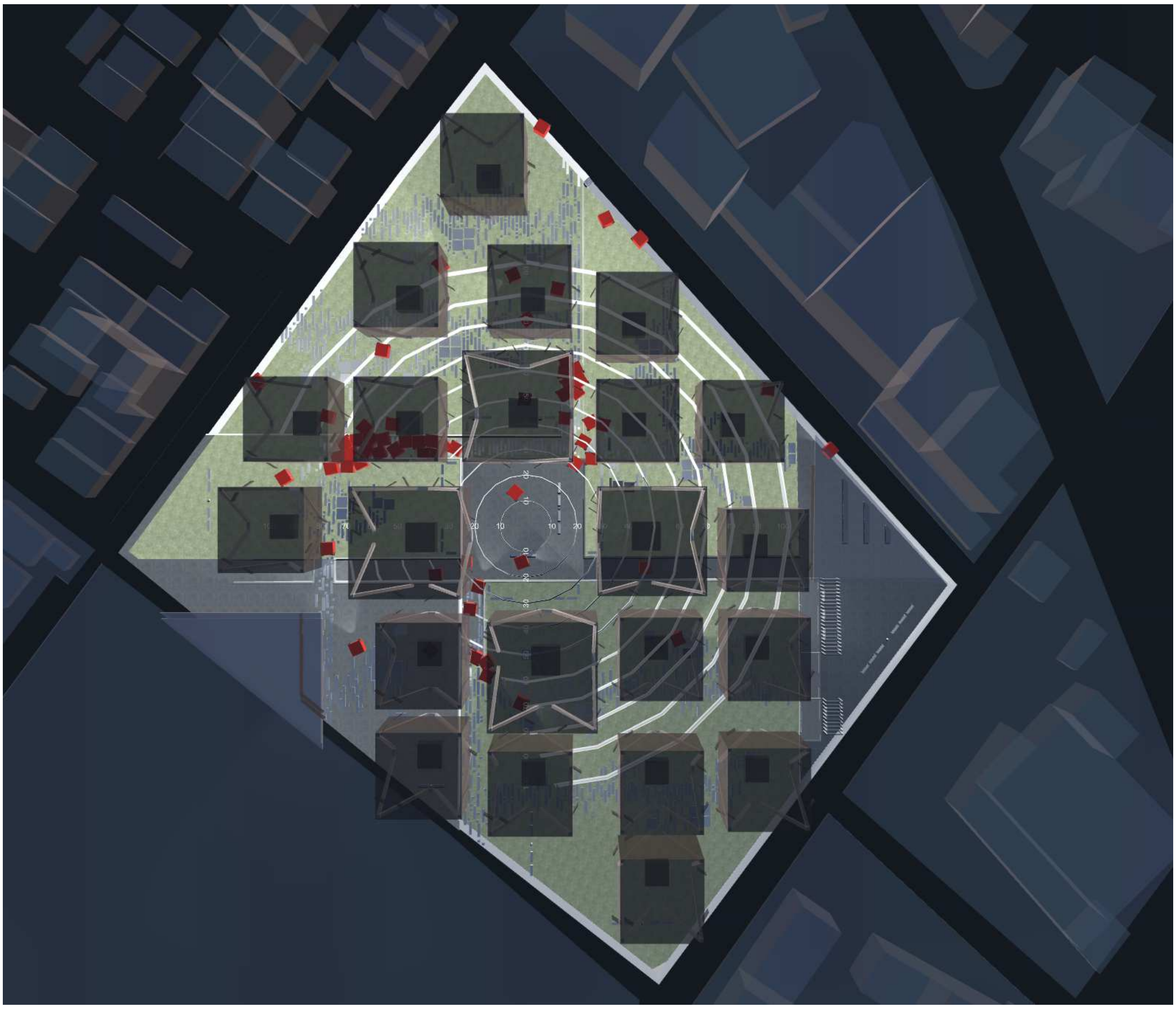
9. I would like to evaluate the urban space I design during my studies by simulating behaviours.

1 point

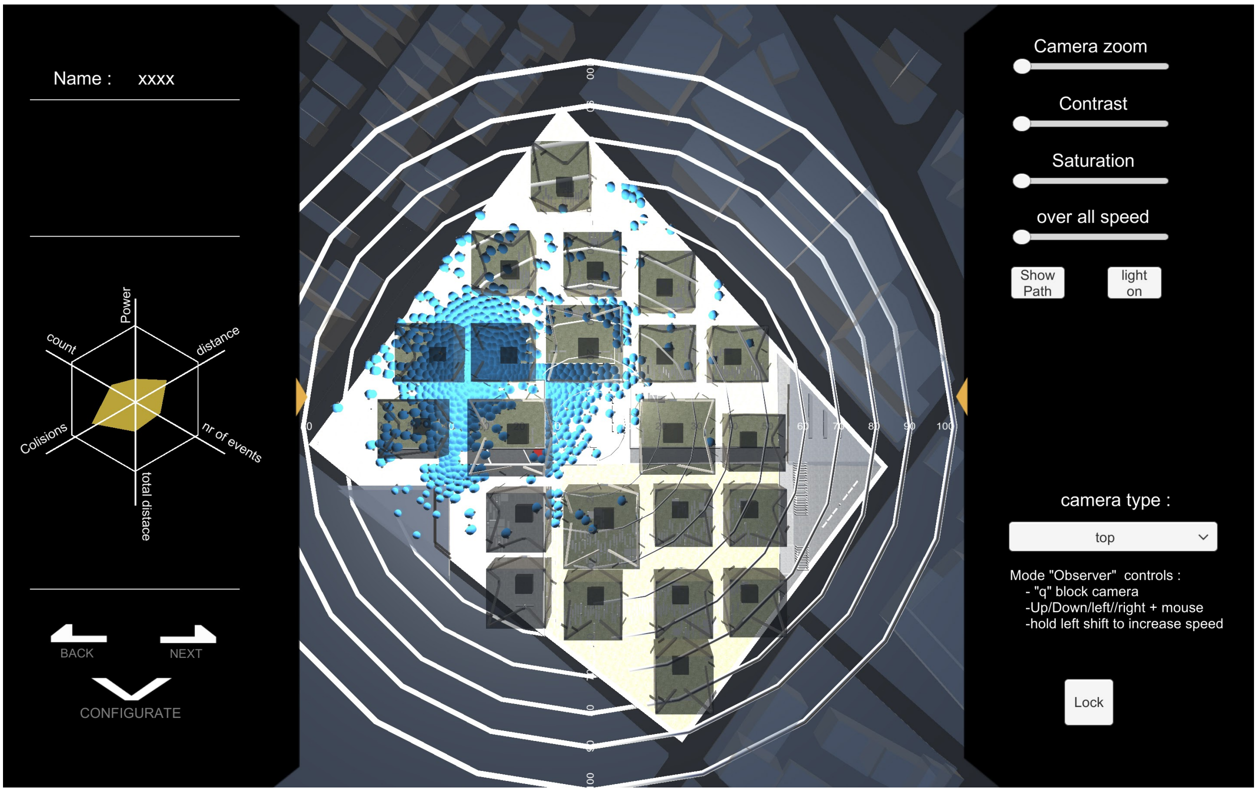
Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Not at all	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	A lot

example 1 of behaviour simulation spawn



example 2 of behaviour simulation spawn



10. The most important thing in architecture is : 1 point

Une seule réponse possible.

- Form
- Function
- Pleasure

Annex 2

Assessment Sheet

Erasmus+ Final Reports Call 2017

KA203 - Strategic Partnerships for higher education

INDIVIDUAL ASSESSMENT

Name of the Organisation:	ASKT
Title of the proposal:	@postasis:Virtual Aristic Laboratory
Reference No:	2017-1-EL01-KA203-036414-Beneficiary Report-2
Coordinator Contact:	Professor TRANOS Nikolaos
Version:	1
Language:	EN

I. ASSESSMENT CONCLUSION

My Scoring
87

Scoring Summary

CRITERIA	SCORE
Relevance of the project/strategy	20
Quality of the project design and implementation	20
Quality of the project team and the cooperation arrangements	12
Impact and dissemination	35
Total	87 / 100

II. ASSESSMENT

Best Practice

The project is to be considered as a best practice	☑

Dissemination

The project implements very effective measures to disseminate and exploit its results	☑
There is a need to improve the quality of the (English version) of the project summary	☐

Impact

The project has a very significant impact outside the participating organisations and individuals	☑

Innovation

The project is innovative (by applying innovative non formal learning methods, tackling innovative topics, developing innovative activities, addressing new target groups or developing innovative tangible results)	☑

Link to youth policy

The project promotes social and cultural diversity	☑
The project promotes cross sectoral cooperation between practitioners	☑

Measures to achieve policy objectives

The project includes activities relating to curriculum development	☑
The project includes activities relating to project-based collaboration with enterprises to study real life cases The	☐
project includes activities relating to embedded mobility (building mobility systematically into the curricula)	☑
The project includes activities relating to better exploitation of ICT, e-learning, virtual mobility and/or virtual learning platforms	☑
The project includes activities relating to approaches to facilitate permeability between education sectors and/or to reduce drop-out	☐
The project includes activities relating to cooperation on support services, such as guidance, coaching and counselling	☐
The project includes activities relating to facilitating recognition of certification of skills through effective quality assurance	☐
The project includes activities which strengthen the links between education, research and business to promote excellence and regional development	☐

Objectives

The project improves the level of key competences and skills of young people	☑
The project contributes to youth employment and the integration of young people in the labour market	☐
The project promotes youth participation in democratic life in Europe and in civil society	☐
The project promotes intercultural dialogue	☐
The project promotes social inclusion and solidarity	☐
The project complements policy reforms at local, regional and national level	☐
The project fosters recognition of non-formal and informal learning	☑

Open educational resources

The project produces materials, documents and/or media that will be made freely available and promoted through open licences	☑

Relevance of the project

The project involves refugees/asylum seekers and/or deals with the theme of refugees' crisis in Europe	☐
The project involves migrants or deals with the theme of migrants' inclusion	☐
The project deals with the issues addressed in the Paris Declaration: anti-radicalisation, citizenship, tolerance and non-discrimination	☐

Type of participants

The project addresses the teaching/learning needs of disadvantaged learners	☑

Results

The project develops tangible results (e.g. materials, documents, products, tools, etc.)	☑

Results / OER

The project produces Open Educational Resources	☑

Annex 3 – ARtect Tests

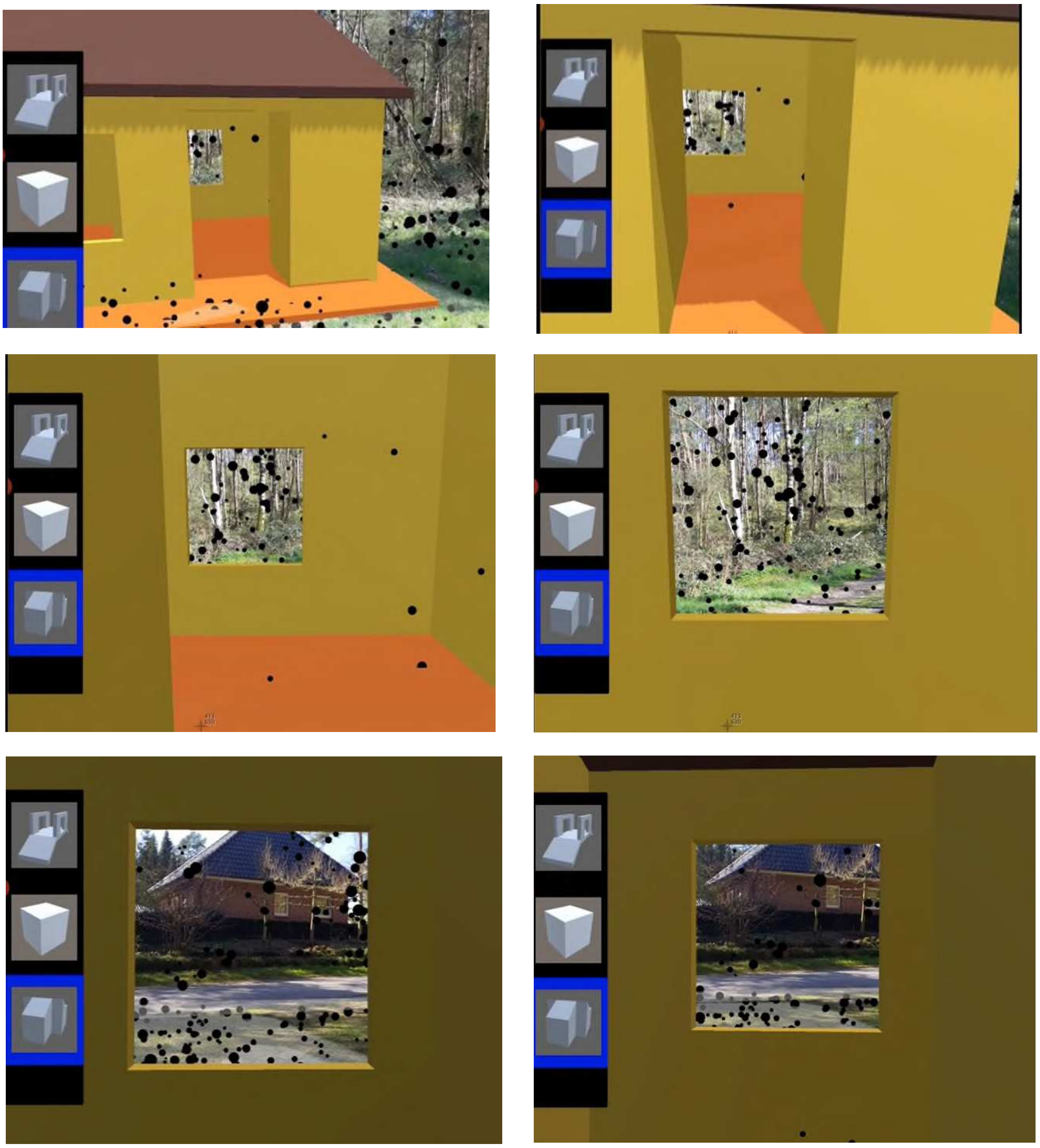


Figure 1. Virtual immersion with ARtect inside a 3D model. The user can navigate and explore the model in AR from different angles while moving in the physical environment.

Figure 2. Experimenting with 2D images of trees (outdoors).

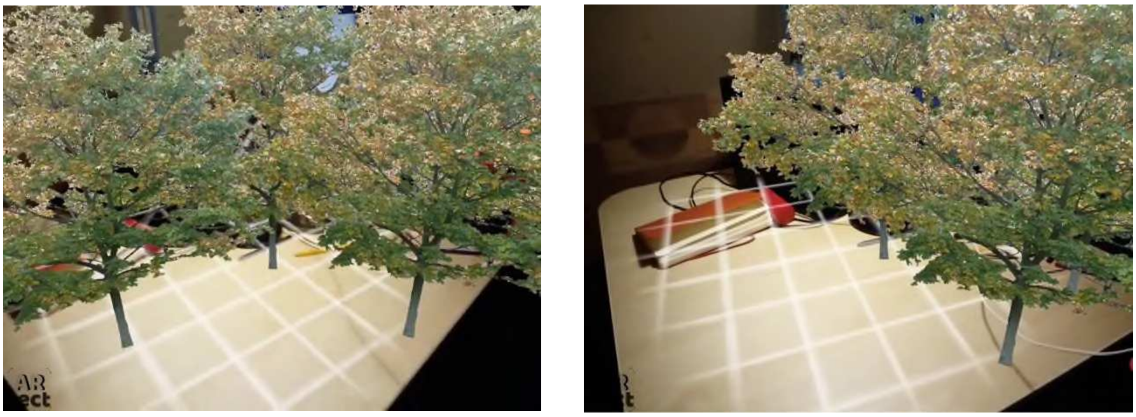


Figure 3. Experimenting with 2D images of trees (indoors).

Figure 4. Placing the 3D model of the Folie N5 in another location and exploring the Ground Floor. The limitation with ARtect is that we can explore only the fround floor for now. Further research is needed so the paticipant can project layers of more floors.

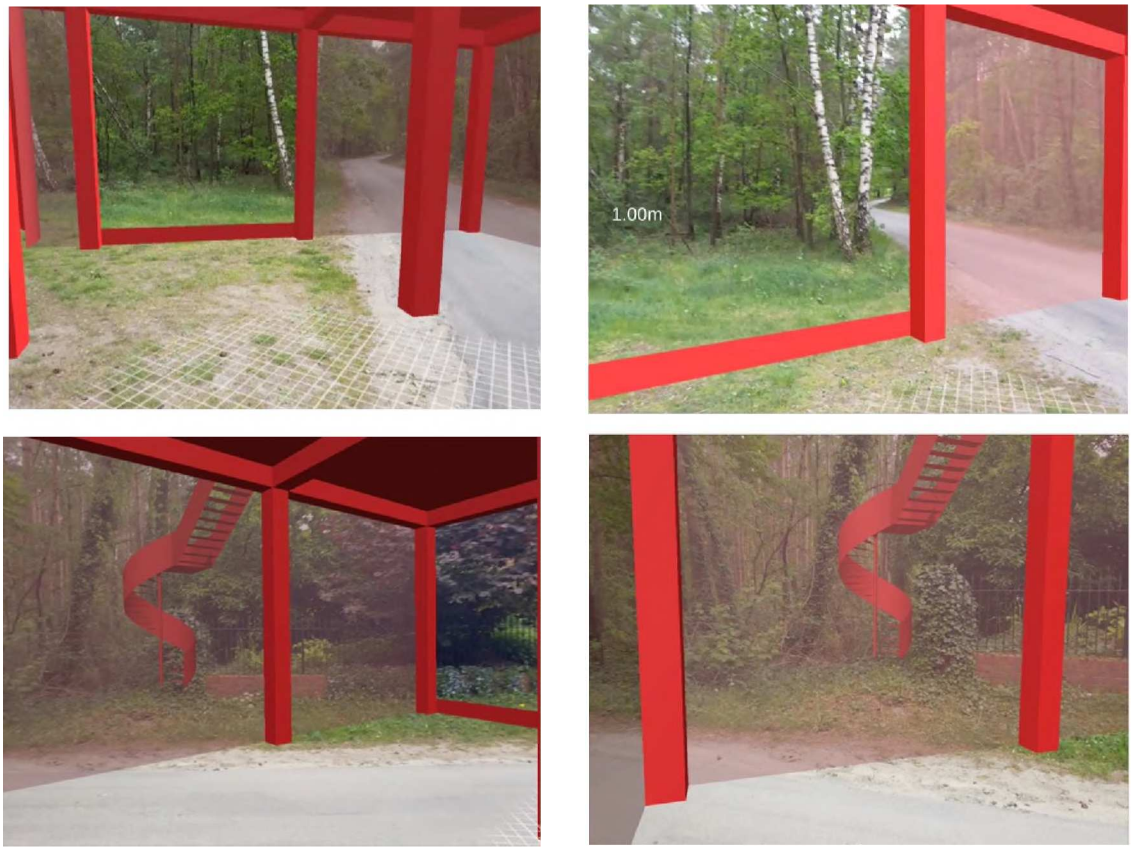


Figure 5. Comparison of lighting, also comparison of the glass material in ARtect using the 3D model of Folie N.5.

Figure 6. Virtual immersion into the 3D model of La Folie N.5, in a different location from the Parc de la Villette. Veryfying the limitations of AR in terms of natural lighting. More abjustemnts in brightness needed.

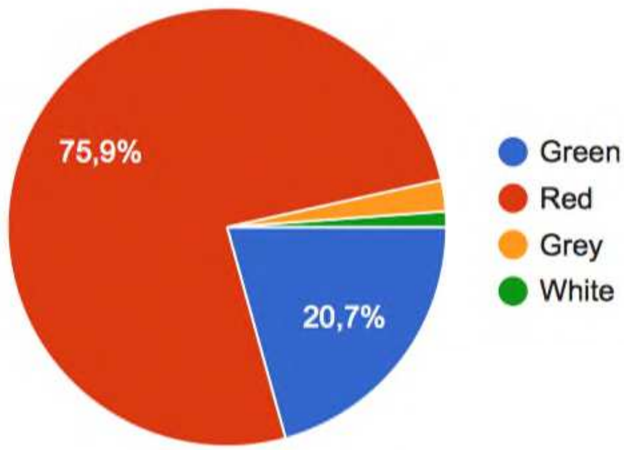
Annex 4

Observation from the author for future research

We showed the image below to architectural students of NTUA (97 participants) and asked them which colour is more pronounced to them, giving them four options:

1) green
2) red
3) grey
4) white

These are the responses of the students:



75,9% of the students said that red is more apparent, and 20,7% pointed out that green is more noticeable. 2,3% said that grey colour is more pronounced and 1,1% declared the white colour.

We put the image to a platform[1] to analyse the colours contained in this image, based on four colour clusters (k-means clustering).

We found out the colour red is only the 3,38% of this image. At the same time, green occupies 36,21% of this image. And grey occupies 47,95 % of this image, which means that is the most dominant colour in this picture; however only 2,3% of the architectural students saw the grey colour as the most dominant.

This is a piece of evidence that Evoked Reality of digital media (in this case, digital image) produces perceptions of reality that are not directly attached to objective reality. The difference of 75,9% of students that picked the red colour in relation to the analysis of 3,38% red colour in the image is quite significant.

This observation is placed here and not inside the thesis because the author claims that the combination of Psychology, even Psychiatry and Neurosciences with the Mixed Reality media in architecture can be proven in the future fruitful.

This information is mentioned here as a start of new research towards the related field, which is based on analysing the subjective perception of images in relation to objective values of facts. This can also impact architectural education. We leave this observation here for future researchers.

Lastly, we attached the analysis of the image based on the online tool.

[1] http://mkweb.bcgsc.ca/color-summarizer/?analyze

IMAGE COLOR SUMMARIZER

RGB, HSV, LCH & Lab image color statistics and clustering—simple and easy

IMAGE COLOR SUMMARY

THE IMAGE IN WORDS

ash azureish battleship blaze blue bluish breathless calm chicago dark designer dreamer geyser gravel green greenish grey half international knave light lilac magnetic military olivish orange pastel pattens red smokey solitude swamp tapa triple white zircon

COLOR CLUSTERS

Colors in the image were clustered into 4 groups (k-means). The average color of the colors for each cluster is shown. The name is the closest named color and its distance is shown using ΔE. The tags are the set of words formed by all named neighbours within ΔE ≤ 5. The list of words above is the set of all unique words in this set of words.

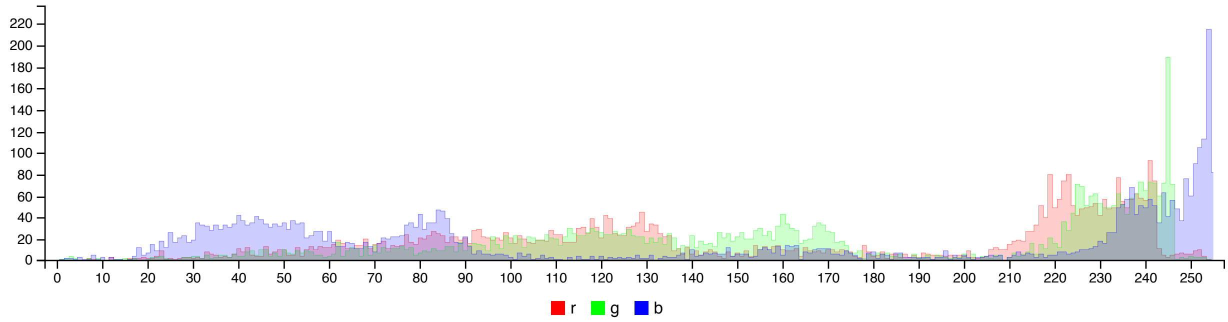
Cluster colors, sized by number of pixels:

cluster	pixels	name	HEX	RGB	HSV	LCH	Lab	tags
	47.95%	224,227,234 half breathless ΔE=0.9	#DCE2EA	220 226 234	216 6 92	90 5 266	90 0 -5	light azureish bluish breathless designer dreamer geyser half lilac pattens solitude zircon blue grey white
	36.21%	105,131,57 swamp ΔE=2.4	#64813C	100 129 60	85 54 51	50 41 124	50 -23 34	military swamp green
	12.45%	91,90,80 triple tapa ΔE=1.3	#595B52	89 91 82	74 10 36	38 6 118	38 -3 5	dark ash battleship calm chicago gravel greenish half knave magnetic olivish smokey tapa triple green grey
	3.38%	194,59,34 dark pastel red ΔE=3.3	#BC3823	188 56 35	8 82 74	44 67 39	44 52 42	dark blaze international pastel orange red

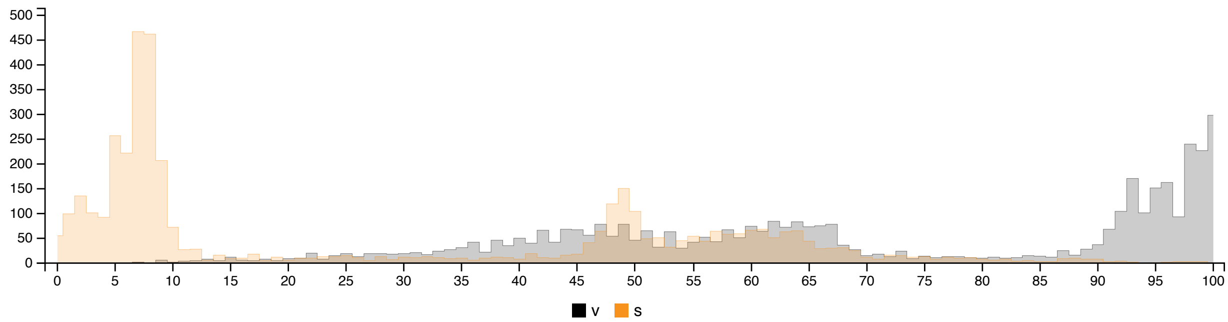
IMAGE CLUSTER PARTITIONS

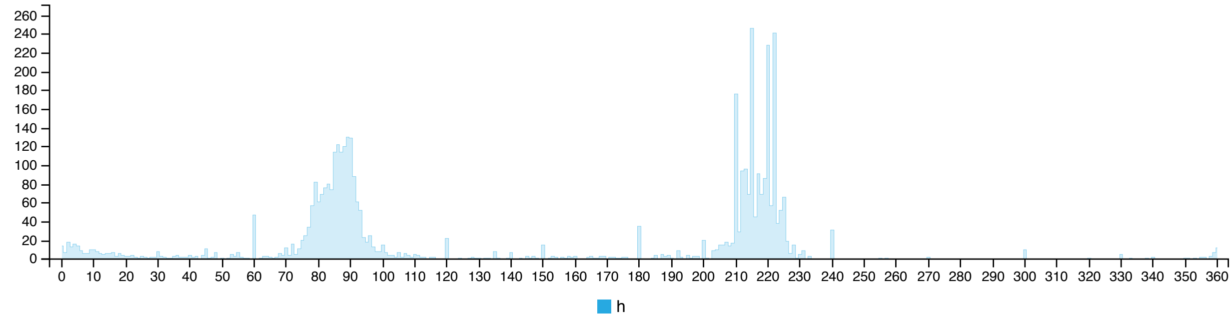
Pixels of the image assigned to each cluster. The border is the color of the cluster as calculated by the average value of its pixels.

RGB HISTOGRAM

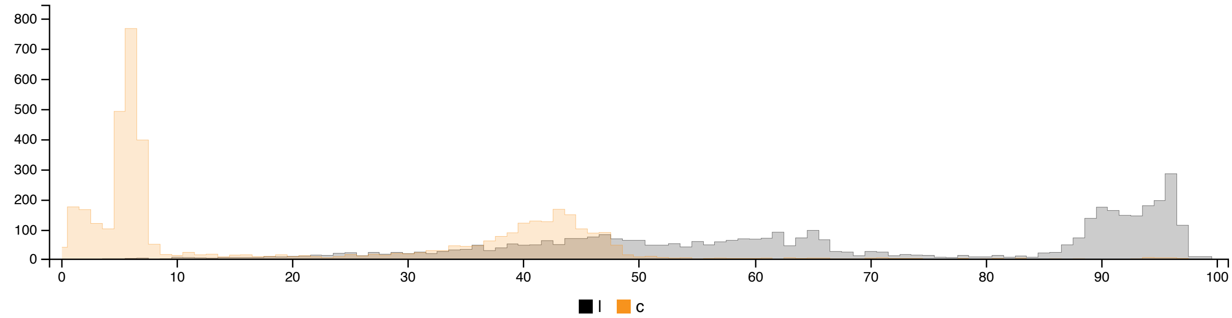


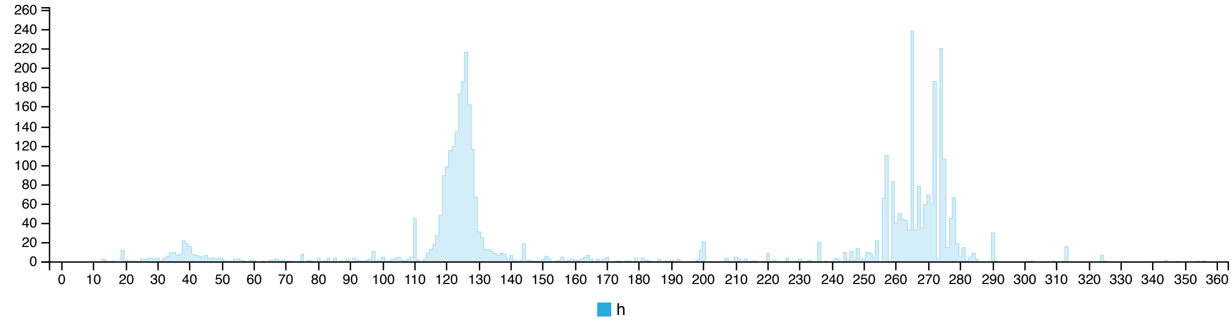
HSV HISTOGRAMS



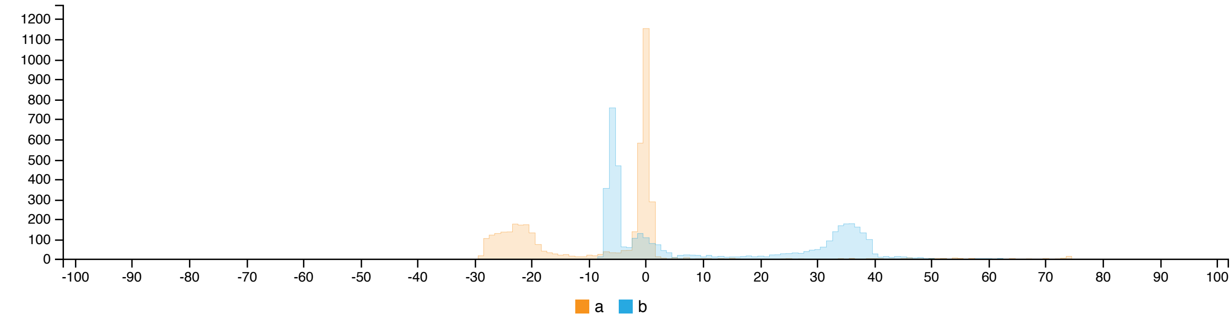


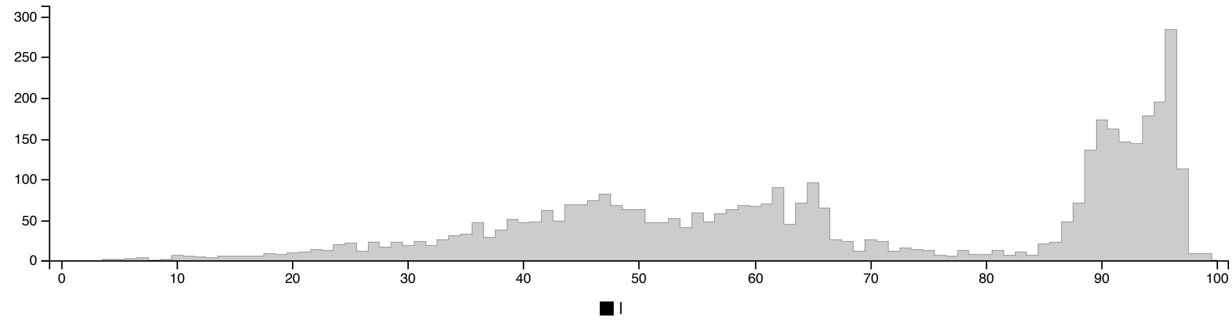
LCH HISTOGRAMS





LAB HISTOGRAMS





COLOR SPACE AND CHANNEL STATISTICS

	avg	med	min	max
RGB:R	160	157	7	254
RGB:G	169	165	1	254
RGB:B	145	144	1	255
HSV:H	148 0.00	134	0	360
HSV:S	29	10	0	100

HSV:V	70	66	7	100
LCH:L	67	65	4	100
LCH:C	21	7	0	97
LCH:H	191 0.00	144	13	356
LAB:L	67	65	4	100
LAB:A	-7	-1	-29	74
LAB:B	12	1	-10	62

Maria VELAORA

Methods of teaching architecture in virtual immersion: Experimentations for the design studio

Résumé

Les réalités numériques, telles que la réalité virtuelle (RV) ou augmentée (RA) peuvent compléter les méthodes traditionnelles d'apprentissage de la conception architecturale. Les possibilités de mixité entre l'environnement réel et virtuel, rendues possibles par la RA, favoriseraient l'appropriation des relations entre l'architecture et son milieu. La RV permettrait de confronter l'étudiant à différentes situations. La thèse vise à contribuer aux usages possibles d'environnements virtuels interactifs de réalités numériques à partir desquels pourraient émerger de nouvelles méthodes pédagogiques d'enseignement de l'architecture. Les transformations des méthodes pédagogiques liées aux technologies numériques échappent totalement à l'enseignement de l'architecture, qui reste fortement ancrée dans la tradition. La méthode de recherche que nous avons développée a consisté à mener des enquêtes auprès d'étudiants. Nous avons développé des applications numériques et nous les avons expérimentés au sein des ateliers de projets. Enfin, nous avons synthétisé ces expériences afin d'identifier les possibilités et les limites de l'usage des réalités numériques et des environnements virtuels immersifs dans l'enseignement de l'architecture.
Mots-clés: apprentissage de l'architecture, réalité augmentée, atelier de projet, interaction, immersion, expérimentation

Résumé en anglais

Digital realities, such as virtual (VR) or augmented reality (AR), can complement traditional methods of learning architectural design. The possibilities of mixing the real and the virtual environment, made possible by AR, would promote the appropriation of the relationships between architecture and its surroundings. VR would make it possible to confront the architectural student with different situations. The thesis aims to contribute possible uses of interactive virtual environments on which new educational methods of teaching architecture can emerge. The transformations in teaching methods related to Digital Technologies completely escape the teaching of architecture, which remains firmly rooted in tradition. The research method that we developed consisted of carrying out surveys among architectural students. Furthermore, we have developed digital applications and tested them in design studios. Finally, we have synthesized these experiences to identify the possibilities and limits of digital realities and virtual immersive environments used in the teaching of architecture.
keywords: architecture learning, augmented reality, design studio, interaction, immersion, experimentation

Résumé en grec

Οι ψηφιακές πραγματικότητες, όπως η εικονική (VR) ή η επαυξημένη πραγματικότητα (AR), μπορούν να συμπληρώσουν τις παραδοσιακές μεθόδους εκμάθησης αρχιτεκτονικού σχεδιασμού. Οι δυνατότητες ανάμειξης του πραγματικού και του εικονικού περιβάλλοντος, που καθίσταται δυνατή από την AR, θα προωθήσουν την οικειοποίηση των σχέσεων μεταξύ της αρχιτεκτονικής και του περιβάλλοντός της. Η VR θα επέτρεπε την αντιμετώπιση διαφορετικών καταστάσεων από τον φοιτητή αρχιτεκτονικής. Η διδακτορική εργασία στοχεύει στη συμβολή πιθανών χρήσεων διαδραστικών εικονικών περιβαλλόντων από τα οποία μπορούν να αναδυθούν νέες εκπαιδευτικές μέθοδοι διδασκαλίας αρχιτεκτονικής. Οι μετασχηματισμοί στις μεθόδους διδασκαλίας που σχετίζονται με τις ψηφιακές τεχνολογίες ξεφεύγουν εντελώς από τη διδασκαλία της αρχιτεκτονικής, η οποία παραμένει σταθερά ριζωμένη στην παράδοση. Η ερευνητική μέθοδος που αναπτύξαμε συνίστατο στη διεξαγωγή ερευνών μεταξύ φοιτητών αρχιτεκτονικής. Επιπλέον, έχουμε αναπτύξει ψηφιακές εφαρμογές και τις δοκιμάσαμε στο μάθημα του αρχιτεκτονικού σχεδιασμού. Τέλος, έχουμε συνθέσει αυτές τις εμπειρίες για να προσδιορίσουμε τις δυνατότητες και τα τα όρια της ψηφιακής πραγματικότητας και των εικονικών εμβυθιστικών περιβαλλόντων που χρησιμοποιούνται στη διδασκαλία της αρχιτεκτονικής.
λέξεις-κλειδιά: αρχιτεκτονική μάθηση, επαυξημένη πραγματικότητα, στούντιο σχεδιασμού, αλληλεπίδραση, εμβύθιση, πειραματισμός.