Virtual and Augmented Reality for Architecture and Design

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Ernesto Filgueiras, and
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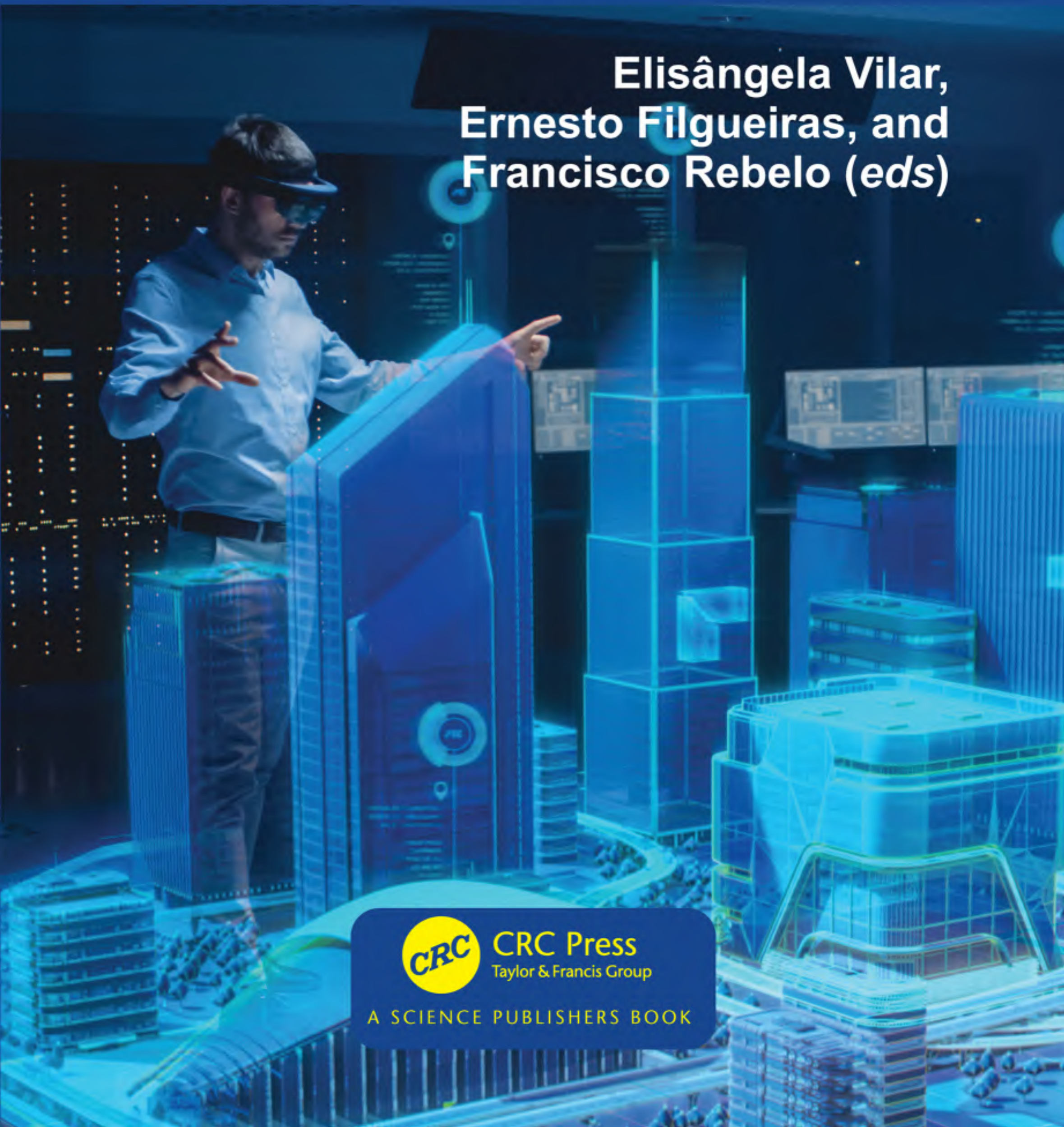

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Preface

Together with Augmented Reality, Virtual Reality is passing from science fiction to a reality in people's daily lives. More and more, new devices and applications are being developed to be used in several fields, from entertainment to health, and the Architecture and Design areas are among those with higher relevance considering the impact of those technologies on their core. Researches on Virtual and Augmented Reality (VR/AR) for architecture and design and their practical application have shown their potential to improve teamwork, multidisciplinarity, communication, prototyping, testing, user experience, and teaching/learning skills. However, as with all new approaches, a lot of work still needs to be done, making this correlation between VR/AR technologies and the Architecture and Design fields of study a stone that still needs to be lapidated.

In addition to research, product interfaces with VR/AR embedded in everyday products and smart buildings should radically change the way we interact with the tangible world, creating new interaction paradigms that should be mastered by designers of the next half of the Century XXI. Thus, the knowledge of the limits and the exploration of its potentials must be one of the main focuses of Architecture and Design in this century, even influencing the development of new methodological approaches.

Thus, our main concern with this book is to bring together several initiatives, from conceptualization to application of VR/AR, in Architecture and Design areas, showing how this is a promising tool to enhance creativity and design skills, communicate the project, test design alternatives with users, solidify knowledge and, most of all, to help all interested in this field to deep in their understanding, providing new conceptual models, methodological approaches, and case studies.

This book is a collection of studies from experts in Architecture and Design areas, such as interior architecture, vernacular architecture, cultural heritage, building construction, smart buildings, safety design, Information design, strategic design, product design, digital media, technology-based design, new media theory, user testing, user experience, and learning and education. All of them having VR/AR as a focal point of their studies, researchers from different countries present and discuss this technology's application in a didactic and comprehensive way.

As enthusiasts of VR/AR technology, we can assume that, in the end, with VR/AR, we are able to provide a funny and reliable way to study, practice, and teach/learn architecture and design-related issues.

Along with nine chapters, this book presents, analyses, and discusses the integration and use of VR/AR within the process of planning, development, and research for Design and Architecture, also relying on case studies and applied research with multidisciplinary collaborative work, with a major concern of being informative and accessible. With a miscellaneous of VR/AR studies from several countries, this book highlights VR/AR application in areas such as education, heritage, research, and methodologies, bridging the gap between Architectural and Design abstraction and Human requirements through technology.

With this in mind, this book is directed to students and researchers who want to initiate in the field of VR/AR, as well as to experts that want to learn more about this area. Also, it is a beneficial tool for professional in Architectural and Design that are interested in applying VR/AR to their projects.

We hope you enjoy it!

The editors

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Virtual Reality in Architecture and Design Twenty Years of Experience

Elisângela Vilar,[1,2,*] *Francisco Rebelo*,[1,2] *Paulo Noriega*,[1,2]
Ernesto Filgueiras[1] and *Emília Duarte*[3]

1. Introduction

The advances and new demands related to Virtual Reality (VR) has made this technology one of the focuses of innovative initiatives for researching in Architecture and Design scientific areas. Many studies have been developed concentrating on both, the technology itself and all the interaction issues that could arise from this, along with its use as a new interaction environment, where it is possible to simulate a paramount of alternatives that would be impossible to materialize in the physical world. In the last two decades, researchers from different areas of expertise got together to discuss and research VR, its use and implications, as well as its application as an interaction environment to develop and/or to access new design paradigms considering the user behavior. With this, in the early 2000s, a group from ergonomics, design, architecture, and psychology framed the ergoUX Lab at the University of Lisbon, and started to focus their activity on VR-based methodologies for Design and Architecture fields, being pioneers in this field in Portugal. From the beginning to now, a body of knowledge about the use of VR for studies focusing on

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the observation of human behavior was built, having developed research of great relevance in the areas of design and architecture, namely for the design of safety signs, way finding in complex buildings, new interaction paradigms in smart buildings, and the development of training simulators.

With this context, this chapter is divided in five sections. The first section is dedicated to the introduction, followed by a second section for an overview of the main concepts related with virtual reality and a third section about VR applications and the research using VR for design and architecture that has been done worldwide. The fourth section presents the ergoUX Lab and its research along last twenty years, followed by the conclusion that will be presented in the fifth section, discussing future trends and expectations.

2. An Overview on Virtual Reality (VR)—Main Concepts and Applications

From 1965, with the Sutherland's "The Ultimate Display", (Sutherland 1965) to the present, VR has evolved and became one of the most promising tool for several areas, such as entertainment, health, training and academic research. With the evolution of this technology, VR/AR devices seems to be the new trend to enrich the way information is accessed and presented (Li et al. 2018), and from a scientific/academic point of view, VR has become a powerful tool to study future scenarios, where new trends can be tested and new paradigms can be created.

VR can be defined as a way of transporting a person to a digital reality in which he/she is not physically present but feels like he/she is (Rebelo et al. 2012). Presence is a key concept to VR. Lombard and Ditton (1997) explored and discussed the concept of presence, and presented six categories for this, mainly related to the field of intervention where the concept is applied to:

i) Presence as social richness—that is "the extent to which a medium is perceived as sociable, warm, sensitive, personal or intimate when it is used to interact with other people";

ii) Presence as realism—that is "the degree to which a medium can produce seemingly accurate representations of objects, events, and people";

iii) Presence as transportation—That implicates the idea of moving from/ to, being this made of three distinct ways: You are there "*in which the user is transported to another place*", It is here "*in which another place and the objects within it are transported to the user*"; and We are together, "*in which two (or more) communicators are transported together to a place that they share*";

iv) Presence as immersion—that highlights the perceptual and psychological immersion, in a way that the senses are immersed in the virtual world, and higher the isolation between worlds higher immersion/presence is.

v) Presence as social actor within medium—that is when the mediation between an actor that is not physically present at the same place as a the user is ignored, making user to react to the actor (even robots or virtual characters) as they were physically together; and,

vi) Presence in the medium as social actor—that is when "basic social cues exhibited by the medium lead users to treat the medium as a social entity".

Witmer and Singer (1998) state that a critical point to the effective use of the VR approach is to provide the users the means with which they could believe that they are in a place, even when they are physically in another, in a way to enhance the sense of presence. Thus, presence can be enhanced by the technology, but also by many other aspects of the interaction, such as the level of details of the virtual environment, and the created narrative and storytelling.

In this sense, immersion is a complementary concept in which the technology is the way to mediate physical and digital worlds, lower the perception of the real world, higher the immersion. So, the lower perception of the real world the user perceives (see, hear, touch), the greater the physical level of immersion (Rebelo et al. 2012). A classification of the types of immersion was proposed by Gutierrez et al. (2008) mainly considering the physical configuration of a VR user interface, varying from fully immersive to non-immersive. Thus, VR can be considered immersive when the interaction is mediated by, for example, a head-mounted display (HMD) and a tracker position sensor, or non-immersive, where the HMD is substituted by an external monitor (Gorini et al. 2011). It can also be considered semi-immersive when large projection screens, for example, are used as the VR user interface (Gutierrez et al. 2008). The interaction with the synthetic world is an important feature of VR and is mainly done through HMD and the CAVE system, for a fully immersive experience, or using large projection screens in which the VE are projected with 3D projectors and visualized with stereoscopic glasses (for a detailed description see Rebelo et al. 2012).

VR has been used in many fields of study, particularly in those in which the understanding of human behavior is the main key for developing solutions to certain issues, such as in design areas, including, product, graphic, architectural and interior design. With VR, simulated situations—many times representing alternatives for the future or situations that could be very difficult to consider in real environments (e.g., fire, subaquatic or spatial situations, medical interventions)—these are developed allowing researchers to study the main impacts on environments and artifacts design, potential user's behaviors, potential risks, and to propose and test new solutions, or creating new paradigms.

According to Vilar and colleagues (2012), one of the most important features of VR is its flexibility to design a lot of diverse and often utopian worlds suitable for the study's objectives and have higher variable control, which is very difficult to achieve when using real-world settings as an interaction environment. Some examples of this are the exploration of virtual environments (VEs) that can be done since from users exploring the virtual world in an egocentric manner (near to the real viewpoint) to flying above the environment to gain an exocentric viewpoint, and to interact with virtual objects, even with those that are unthinkable in real situation (e.g., moving walls, crossing a fire, breathing under water, flying). Nowadays, realistic-looking virtual environments combined with high engaged narratives allow a great control of experimental conditions and variables, while grating good ecological validity and replicability. Other advantages are the availability of avatars and/or embodied agents, which can assume the researcher's or confederate's role but with rigorously controlled behavior (Rebelo et al. 2012), and the automatic registration of all user's interaction behaviors (e.g., paths, pauses, eye movements).

Covering a wide range of computer-mediated techniques and technological devices, VR allows users to be transported to a synthetic environment in which they are able to interact with it without being physically present (Teixeira et al. 2011). The interaction with VE has been successfully used for research in several fields of study such as Social/Cognitive Psychology, Ergonomics, Architecture, Design and Engineering. A variety of technological solutions can be found to fulfil researchers needs, from sophisticated Head-Mounted Displays (HMD) with 210° of field of view (i.e., Star VR/IMAX) to cardboards HMD (e.g., Google Cardboard), or even AR apps developed for mobile smartphones that can be easily created since the launch of the ARKit (for IOS system) and ARCore from Google.

Many advantages of VR systems are pointed out by authors (e.g., Jansen-Osmann 2002, Mantovani et al. 2001, Vilar et al. 2014a, Vilar et al. 2013b), such as: its cost-effectiveness when compared to the construction of physical setups; the control of the study's variables are easier and more rigorous; the experience's replication is facilitated; it provides scenarios that otherwise would be difficult/impossible to access (e.g., hazardous environments); important data can be automatically recorded; the system setup can be easily changed according research need; its use may overcome some ethical issues that may arise in human behavior research.

3. VR Research and Applications

Nowadays, VR devices can be found in places ranging from amusement parks in radical roller coasters to sophisticated scientific laboratories helping researchers to understand and answer advanced issues. According to Li and colleagues (2018), users are able to realize the highly immersive, holistic and realistic experience supported by a digital and physical world information, instead of just interact with 3D contents in a pure computer-generated environment.

The market is full of VR devices and applications, with different levels of experience and immersion and it is in growth. Reports about the global VR market (Fortune Business Insights 2020, Grand View Research 2020) point a VR market size valued in more than U$ 50 billion at 202, mostly boosted by the growing popularity of BYOD (Bring Your Own Device) concept in the United States market and by key factors such as technological advances, penetration in the consumer electronics industry, and the rising demand for virtual training across industry.

Among the contributions that technology is making to these sectors, Virtual Reality (VR) is creating immense opportunities for the leisure and tourism industries throughout the pre-visit phase, during the trip and at the post-visit stage (Marasco and Balbi 2019, Tussyadiah et al. 2018).

From an academic research point of view, the number of studies that consider VR-based methodologies has increased substantially. In a review made considering published papers in construction area from 2000 to 2017, authors point that the number of studies using VR-based methodology passed from 1.5 papers per year in 2000 to 8 papers per year in 2017 (Li et al. 2018). In another review made by Seth et al. (2011), considering the use of VR-based methodology for products prototyping and evaluation, authors found several applications developed for virtual assembly (for detailed review see Seth et al. 2011). Authors argued that as VR provides an "invisible interface" for users' interaction with VE as they would be interacting in the real world, it makes VR-based methodologies perfect for prototyping and evaluation of products. With VR, simulating tasks that require intuitive and frequent manual interaction such as assembly methods prototyping, can be made reducing the need of physical assembly resulting in a more encompassing design decisions (Seth et al. 2011).

The research and construction industry has been given a considerable amount of attention to VR in construction safety in the last two decades. According to Li and colleagues (2018), there has been an increase in sophisticated immersive Virtual and Augmented Reality applications to develop environments for people to visualize and interact with complex work situations, in order to acquire a risk-preventive knowledge. It is possible because many developed VR/AR systems have been tested and proved as efficient, usable, applicable and accurate approaches in many fields related to safety, such as hazards identification, safety training and education, safety inspections and introduction (Li et al. 2018).

VR/AR-based methodologies have been widely used also for training purpose, mainly for those who act in highly demanding/costly situations, such as fire fighters, surgeons, trainee physicians, among others. In a study carried out by Williams-Bell and colleagues (2015), twenty-one systems were found on a literature review about serious game and virtual simulations for training in the fire service. According to the authors, firefighting simulations have their focus primarily on training, mainly directed to train recruits and incumbent firefighters for breathing apparatus entry, systematic search of a smoke filled building, or fire suppression, communication and leadership on the fire ground, and fire safety education (for more detailed review, see Williams-Bell et al. 2015).

In a VR-based fire simulator developed by Cha and colleagues (2012), firefighters are able to train at an entry level, and to assist firefighting commanders in the assessment of some fire scenarios, allowing them to take safe decisions and make appropriate fire ground plans. In this simulator, general users are also allowed to experience a simulated real fire situation.

With users being inserted in the core of the design process, through methodologies such as User-Centered Design (International Organization for Standardization 2010), Participatory Design (Sanders 2003, Schuler and Namioka 1993) and Experience Design (Sanders 2003), the need of methods and tools to understand users' behaviors, needs and expectations increased.

The International Standard ISO 9241-210:2010 (International Organization for Standardization 2010) presents the iterative process of User-Centered Design and outlines the phases through a design and development life-cycle. At the same time, it is focused on gaining a deep understanding of the user and their needs in each phase of the design process, challenging designers to mold the interface around the user's capabilities, needs and expectations. On Participatory Design, users and all stakeholders are involved more deeply in the design process as co-designers, empowering them to propose and generate design alternatives themselves.

According to Bruno and Muzzupappa (2010), even though the effectiveness of process involving users' participation, such as User-Centered Design and Participatory Design processes had been well documented in literature, some limits were also pointed. Those limits are mainly related with the need of physical mockups or expensive prototypes as most of users are not able to understand theoretical concepts and prefer to discuss existing products or detailed mockups. Authors also point out that users and designers do not share, in general, the same language, having different cultural backgrounds, making communication more difficult. There is a lack of tools that are able to simplify designer-users communication in order to quickly acquire feedback, ideas, suggestions and a performance evaluation (Bruno and Muzzupappa 2010).

In this way, in a iterative design process in which users participate actively in several phases, providing the design team a deep understanding of their needs, capabilities and expectations, the use of VR systems could represent a great advantage. According to Tideman and colleagues (2008), there are many methods and tools that were developed that support the creation of good product, and the main trends are the VR systems, gaming principles and the use of scenario-based techniques during the design process.

4. The ergoUX Lab

The ergoUX Lab arose from the evolution of the ergoVR group, firstly located at the ergonomics department of the Faculty of Human Kinetics at the Technical University of Lisbon, created in the early 2000s, and led by Professor Francisco Rebelo. At this time, VR was still a glimpse of what it is now, being of the first groups, one of the pioneers in studying the human behavior in a User-Centered-Design perspective for the design and evaluation of new solutions for products and environments. In 2019, the ergoVR was transferred to the Faculty of Architecture of the University of Lisbon and change its name for ergoUX Lab, maintaining its core research as well as its established team.

Nowadays, most of the research activity developed at the ergoUX Lab covers: (i) the traditional Ergonomics, related with workplace design solutions, using digital humans to create new workplace solutions; (ii) Usability and Human Experience research area, developed to give new solutions to the new challenges from the industry 4.0 to smart cities; (iii) Emotional Design research, that covers the emotional reactions that result from the Human interaction; (iv) Game and Gamification research area, in which the game mechanisms are studied to give enough challenge to user's skills and recognized renewals, that absorb the user in the game activities reaching to a subjective experience of total involvement with the game; and, (v) Virtual Reality, used as a tool to optimize design solutions, through the evaluation of human behavior in interaction with the elements of a virtual system.

Thus, ergoUX lab has focused its research on the integration of human behavior knowledge on the design and evaluation of products, services and environments, mainly integrating research on human behavior and VR. It is now current knowledge that emotion plays a fundamental role in human decision process. Thus the design process must include tools to evaluate emotions in interactions with objects in the world, which can be physical or virtual. With this in mind, the ergoUX Lab has been linking the established areas of Architecture and Design with emergent theories of emotional design and gamification, mediated by VR as the interaction environment with the mission of creating value in organizations to make people's daily life more fun, healthy and safe.

At the ergoUX Lab, the presence concept is in line with the Presence as transportation, also agreeing with Witmer and Singer (1998), highlighting the importance of the technology, but also the many other aspects of the interaction, such as the level of details of the virtual environment, and the storytelling for a created narrative. For this, a great effort in developing and validating these aspects is done by the team, as they are understood as the core factor for the success of a VR-based study to create engagement, and enriching the experience.

Considering the VR devices used, at ergoUX Lab, most of the research is carried out considering a fully-immersed VR setup, combining the use of HMD with motion sensors. Many systems were already tested and used by the team, such as the Sony® PLM-S700E, the piSight, xSight and zSight, from Sensics, the first and second generation of the Oculus Rift, the HTC Vive system, and more recently, the Oculus Quest. Also, experiments were done considering a semi-immersive approach, with the use of large 3D projections in a fully dark room. The motion into the VE was also a matter of concern, been used from joystick to an in-home setup using flock-of birds sensors. As technology evolves very quickly, the ergoUX Lab team is committed in to suit the real demands of the research to the required technology, in a way to guarantee a high cost/benefit standard, and its spread among the academic community in which the lab is inserted. So, students are highly encouraged to use the available devices to develop their own research.

4.1 Main VR-based Research at ergoUX Lab

Since its creation that, the ergoUX Lab, VR-based methodologies are considered as the golden standards to investigate and understand users' behaviors, define trends, and test design solutions against users' requirements, adopting VR as a tool to examine design principles and concepts and to create new paradigms. Along almost twenty years, the research developed at the lab covers topics such as safety information and emergency signs evaluation and design, way finding into complex buildings, household products package design, hospital room and offices interior design, virtual exhibitions and museums, interfaces for VR, among others.

One of the first studies considering a VR-based methodology developed by the ergoUX team was carried out in the early 2000s (e.g., Duarte 2010, Duarte and Rebelo 2007, Duarte et al. 2014, Duarte et al. 2010) in which the behavioral compliance of dynamic safety signs was compared with static counterparts during a work-related task and emergency egress. For this study, ninety participants were asked to interact in an immersive virtual reality environment in order to perform some tasks. Cued and uncued safety signs were posted into the virtual environment and compliance with these signs was assessed prior to an explosion/fire involving egress with exit signs. According to the authors, dynamic presentation produced higher compliance than static one. However, the difference between both presentation types was only statistically significant for uncued signs. Findings were explained by authors in the light of the sign salience and task differences. According to the authors, salient signs (e.g., dynamic) are useful when signs must capture attention while individuals are attending to other tasks.

Wayfinding and environmental affordances, key aspects for architectural design, were also investigated using VR-based methodologies by the ergoUX Lab team (e.g., Vilar 2012, Vilar et al. 2014a, Vilar et al. 2014b, Vilar et al. 2013a, Vilar et al. 2015, Vilar et al. 2010). An example is the research carried out by Vilar (Vilar 2012) in which the affordances concept was considered as an approach to study the individual movement indoors. It considers that some environmental variables, such as the corridors width and brightness, can act as factors of attraction, improving corridors affordance and influencing the spatial decision. Figure 1 presents examples of virtual environments developed to study environmental

Figure 1. The top images show an example of virtual environment used to study corridors' type and width, and the bottom images presents examples of virtual environments developed to study corridors' brightness.

affordances, such as corridors type, width and brightness. Directional signage was also discussed as explicit information that directly informs a path. Figure 2 presents an example of a virtual environment developed to study compliance with directional signage. The main goal was to contribute with a better understanding about the human wayfinding behavior indoors to define recommendations for optimizing the usability of complex buildings. The use of signage and environmental variables as explicit and implicit information in directing people within complex buildings was investigated, considering daily and emergency situations. A VR-based methodology was used in three experiments. Results indicated that, when signage was absent, the environmental variables were able to direct people towards a specific destination in both, daily and emergency situations. But, competing with posted signs, environmental variables were not so efficient. During an emergency egress, static ISO-type signs were not enough to lead people to a safe place when competing with the environmental variables in the studied conditions.

Figure 2. Examples of virtual environments used to study behavior compliance with directional signage.

To support the research developed by the ergoUX Lab, studies considering technological issues are also focus of interest by the team. Those are mainly centered on data acquisition (Teixeira et al. 2010a, Teixeira et al. 2010b), interaction devices (Teixeira et al. 2012b), and data visualization (Teixeira et al. 2012a). Figure 3 shows an example of the space exploration matrices given as an visualization output by the data acquisition software developed at the ergoUX Lab.

In product design field, VR-base methodology was used with the objective to examine the extent to which the package's shape can implicitly communicate the hazard level of its contents. Thus VR was used to study the effect of package shape on hazard-related user's perception. Main results showed the 3D prototypes of low levels of details packages (only the shape was considered) were enough for the participants to realize

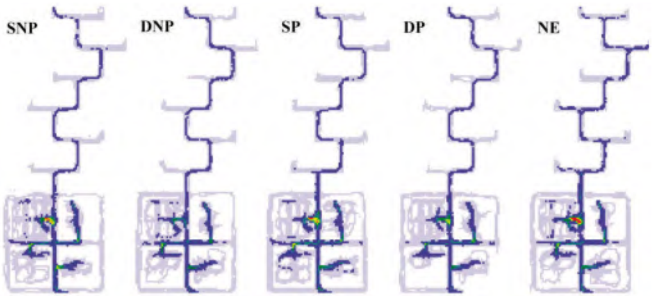

Figure 3. Example of space exploration matrices.

different levels of hazard. Participants were more accurate for familiar packages than for unfamiliar ones when hazard-related perceptions were analyzed, even when only the hazardous packages were considered. Findings suggests that package's shape plays an important role in communicating risk information as it can give cues about the content and its associated level of hazardousness. So, users might face a higher level of risk when dealing with new designs that do not follow well-known patterns (Ayanoğlu et al. 2016, Ayanoğlu et al. 2013).

More recently, the ergoUX Lab is focusing its research on the understanding of users emotional reactions to design features on products and environments, as well as the use of biosensors for studying human response to architecture features to understand the effects of the environment on users (neuroarchitecture), considering data acquired from VR-based methodologies.

An example is the research developed in the interior architecture field, related to the user's emotional reaction into a hospital room (Dinis et al. 2013). For this study, a short version of Zipers scales (Zuckerman 1977) was used to explore participants' emotional responses after interacting with virtual hospital rooms. The independent variables were interior architecture elements (i.e., landscape posters, paintings, plant and home chairs). Thirty university students participated on this study, and the main results show that the more elements are present, the more positive the emotional response is. The landscape and artwork elements emitted positive responses, whereas the home chairs did not.

Biosensors were used to acquire participants information in a study that aims to evaluate the effect of nature-related elements at offices interior design on visitors' anxiety (Vilar et al. 2020). For this, a first job interview situation was simulated in a non-immersive VR setup. A narrative developed to provoke high anxiety level was used to engage users with the scenario (Borges et al. 2015). Self-perceived interview anxiety and emotional arousal were analyzed considering the interaction of sixty-three volunteers with a virtual job interview. Main findings

Figure 4. Virtual environment developed to study the impact of nature-like surrounds on people's anxiety.

suggest that the presence of nature-related elements (i.e., plants and views of green areas) can positively influence interview anxiety for men, whereas they negatively influence interview anxiety for women.

5. Conclusion

In the last decade, investments in developing VR technology made available the required software tools and hardware platforms to create immersive VR experiences, disseminating its use even in an domestic environment, allowing the public to have contact with this new paradigm to interact with the world. Headsets, which used to be expensive and difficult to set up and use—and thus were mostly used by specialized technicians at laboratories of university or large companies for research and development—are now connected with game consoles, such as the Sony PlayStation VR, to offer home entertainment. From the presentation of the first prototype of the Oculus Rift headset in 2010 by Palmer Luckey, the interest in VR was refreshed. The general use of VR was again speculated, with authors pointing to the use of VR for research, but also for commercial and entertainment purposes (e.g., Desai et al. 2014), and investment on VR was boosted, in a way that in 2014, the Oculus Rift was bought by the Facebook. Cipresso and colleagues (2018) corroborate with this stating that low cost VR devices are attracting attention and that they may be *"the next largest stepping stone in technological innovation"*.

Additionally, considering humans in the center of the design and architecture processes are of paramount importance to develop products, systems and environments that meet their requirements and expectations. For this, the understanding and anticipation of human behavior while interacting with new paradigms for products and environments puts VR in the center of the methodologies for development/planning and evaluation in design and architecture fields. With the spread of VR technology among the general public, it is also expected that the expansion of VR use also for facilitating the projects communication among stakeholders. With this, architects and designers can communicate their work to engineers, investors and consumers in a more efficient way, surpassing the problem of developing a mental image of the future building/product by non-experts. With VR, the project can be experienced in first person before execution, facilitating the dialog among all professionals involved and also promoting in costumers and/or decision makers a more accurate perception.

As already pointed, at the ergoUX Lab, VR has already been used in many fields of intervention, particularly in those focused on acquiring the human behavior during the interaction with products, services and environments, promoting an iterative research and development cycle in a way to outline the future of new paradigms for design and architecture. For the future, it is expected to merge environmental sensors and biosensors to study more accurately human perceptions and behaviors, as well as to promote a more suitable human-building/product interaction.

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2

Virtual Reality Technology Trends Current and Future Applications, an Interdisciplinary Overview

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1. Introduction

This chapter aims to investigate the impact of Virtual Reality (VR) in the fields of Architecture, Engineering and Construction (AEC) in both academia and industry as two interdependent and interlinked domains. This chapter is depicting the importance of the utilization of VR technology in both the AEC education and practice. As decision making in the AEC industry involves several stakeholders, starting from professionals to the general public, VR makes it possible to simplify the interaction amongst all of them, and therefore better decisions could be realized. The chapter is divided into five sections, as shown below:

1. Introduction
2. Education for Practice: VR Application in Architectural Engineering Design Studios.
3. A Journey of Parametric Architecture from Academia to Industry and the Connection to Virtual Reality.
4. Application of VR in Civil Engineering.
5. VR and the HVAC Systems.

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The second section presents a successful case study for the application of VR in an architectural engineering undergraduate program. In one of the building design studios, students were introduced to the VR technology in the early stage of the design through a pre-prepared teaching and learning process that transformed the conventional delivery method of learning through the use of both BIM and VR tools. The transformed delivery process has been noticeably helpful for the students in not only in understanding the qualities of the architectural design but also in its associated engineering systems. As VR is shaping the future of AEC practices nowadays and in the future, such a transformed approach could be a role model for other architectural design studios that could better prepare the students to face such practical challenges when they join the AEC industry market after graduation.

In the third section of the chapter, VR is analyzed for the impact it has in the civil engineering discipline. Thru the literature overview there is a critical approach to the current and future applications. The investigation goes further into the construction field, into the underground utilities, and then to have points of reflection on the matter. The use of technology saves time and cost for the industry in the applied projects by detecting errors in early stages. The use of several tools is required to make this process more efficient. Therefore VR and AR have to be integrated with other tools for the pre-processing and post-processing procedures to be elaborated faster and with a high quality of the outcome.

The fourth section makes an investigation on the impact of VR technology in the HVAC systems. Although they are part of the construction, the complexity of the discipline required a separate section bringing more attention to the matter. From the training in university classes to the application on the sites of various projects, this technology enables professionals to understand and take action accordingly to the complex problems that might occur. The impact that the technology has is relevant in large and small scale projects, from the Oil and Gas industry to the residential buildings.

The fifth and final section enters more into the current and futuristic approach of VR technology. Parametric Architecture is a new language, which is expanding more and more in the last few decades. Combined with AI and machine learning, VR can have a bigger impact in showing the progress of this path of architecture. Trials in forms, optimization, innovative materials, 3D printing, digital fabrication, etc., bring new challenges into the field of architecture and construction. Thru the VR technology, this path of architecture can be shown to not only professionals from different disciplines but also to the stakeholders of the industry and the broader public interested in technology and innovation.

VR and AR are areas of technology that have seen rapid development and growth over recent years. VR is the use of computer technology to create a simulated environment. VR simulations are tools that allow users to visualize project outcomes and potential errors. However, it is essential to ensure that the location and terrain data are current and detailed in order to minimize errors and improve results. In essence, the closer the geospatial data is to real-life data, the more accurate the results will be. AR, on the other hand, is a technology that allows engineers to superimpose computer-generated images created in CAD or building information modeling (BIM) software onto a user's view of the real world, which creates a composite or augmented view and, therefore, bridges the gap between real and virtual space. As such, AR combines the physical world with computer-generated virtual elements. In engineering applications, these elements are then projected over physical surfaces in reality within the engineers' field of vision, with the intent of combining the two to enhance one another. While VR covers and replaces the engineers' field of vision entirely, AR projects images in front of them in a fixed area. These technologies can deliver enormous experience and benefits to the various engineering fields. The term extended reality (XR) encompasses VR, AR, and mixed reality systems (Adăscăliţei and Bălţoi 2018).

According to a new study published in a business article by The National (2020), AR and VR are expected to contribute $1.5 trillion to the global economy by 2030. Finland ($7.8 billion), Germany ($103.6 billion) and the UK ($69.3 billion), for example, are set to see the most significant impact from AR and VR on their economies, with the technology adding 2.64%, 2.46%, and 2.44%, respectively to their GDP by 2030. According to the same article, VR and AR will together pump $4.1 billion into the UAE economy by 2030, boosting the country's gross domestic product by 1%. AR and VR will also have a significant impact on employment in the UAE, helping to create more than 42,000 jobs in the country over the next ten years. According to the article, AR and VR technologies will improve how organizations operate, make for a seamless transition to more effective processes, and educate people more effectively. The UAE, for example, will see a 0.95% increase in GDP from VR and AR by 2030 (Sharma 2020).

2. Education for Practice: VR Application in Architectural Engineering Design Studios

In architectural education, Virtual Reality (VR) is principally the technology that aims at immersing the students inside a virtual 1:1 scale space where they can experience and navigate that space as if it is a real-world to their senses. VR is increasingly gaining momentum in architectural design education in a way that helps with better preparing the graduating students for industry. By investing in working within, an as immersive VR experience and dedicating needed time and energy in doing that, these graduating students as architects or architectural engineers will be more capable of designing built environments that reflect considerable awareness of architectural and building systems of quality and integration. Immersive VR technologies are strongly expected to prevail in the near future, changing the nature of the architectural design discipline and its related educational methods (Rodriguez 2019) forever. While the immersive VR tool can significantly help the students develop their design projects a more articulated manner, it can also inform them about the famous architectural works of pioneering architects through virtual tours around the world to explore various architectural styles and forms from the comfort of a design studio (Rodrigues 2019).

Until today, most of the world's experience has been focusing on the implementation of immersive VR in developing teaching and learning methodologies of architectural design, where the significant concentration is chiefly devoted to enhancing the students' abilities in the design of architectural spatial experiences (Angulo 2015). In contrast, very little is known about the experience for the implementation of VR applications in *architectural engineering* design education (Ahmed 2020). In architectural engineering, the building design relies on multiple systems that significantly exceed achieving the merits of architectural design in terms of space and form, and to additionally include the integration of technical systems within the building designs.

The Architectural Engineering (AE) Undergraduate Program at the College of Engineering, United Arab Emirates University (UAEU) is a typical five years ABET-Accreted Program that is committed to achieving the Program Learning Outcomes (PLOs) as defined by the ABET. According to the ABET Engineering Accreditation Commission (2019), the AE graduates are expected to consider the basic concepts of architecture in the context of architectural/building design (ABET Engineering Accreditation Commision 2019). So, while working within the overall architectural design, building design should consider the systems or processes from other architectural engineering curricular areas, include computer-based technology, consider applicable building codes and standards, and finally consider fundamental attributes of building performance and sustainability. To satisfy the ABET accreditation requirements, the AE Undergraduate Program at the UAEU has selected *building construction* to be at the main *Design* attainment level, followed by the *building structure* at the *Application* level and finally the building *electro-mechanical* systems at the *Comprehension* level. In the AE Building Design Studios, students are required to work according to this attainment hierarchy for their architectural engineering design projects.

2.1 VR as a Teaching and Learning Tool in Intermediate Building Design Studio, UAEU

Among the core/compulsory courses of the curriculum of the AE Undergraduate Program, there are 4 building design studios in addition to the capstone graduation project. In each of these design studios, the registered students are required to develop a building design project in one term. This chapter introduces the case of transforming the delivery method of the third design studio course: Intermediate Building Design Studio (IBDS), from the traditional teaching and learning method to the VR integrated one. The IBDS course comes after the necessary course of 'Introduction to Architectural Engineering' and the 'Introductory Building Design Studio' course. Figure 1 below demonstrates the IBDS course description, its three Course Learning Outcomes (CLOs), and their correlation with the ABET Program Learning Outcomes (PLOs).

To make sure that the students are ready to meet the CLOs of this design studio, students should have finished or at least co-register the two courses of 'Analysis and Design Principles for Building Structures' and 'Building Construction Methods and Equipment'. The course has 6 meeting hours in the design studio distributed over 2 days per week, each with 3 hours of meeting time. In their first week, the students are given the usually middle size building design brief for their term project with the course syllabus. The students should develop their design projects individually over 15 weeks (1 Semester). According to the course syllabus, the students should develop an *integrated* architectural engineering design that, while considering the essential architectural design qualities of form, shape, style, space distribution, and organization, should also consider

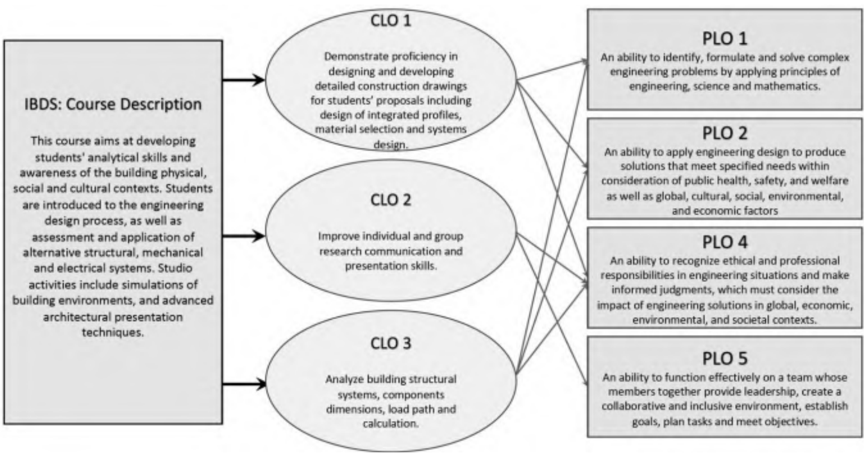


Figure 1. Intermediate building design studio course description, CLOs and PLOs.

the appropriate building construction and structure systems in a well-articulated and elaborated manner.

The IBDS was traditionally taught through developing 2D CAD plans, sections, and elevations based on a formulated architecture concept. The course instructors used to ask the students to print their design drawings on white A1 or A2 size sheets to give them their feedback on the design drawings through freehand sketching. Final design drawings were to be printed out and mounted over the class walls for jury members to discuss and evaluate in both mid-term and final term juries.

2.1.1 IBDS Transformation Process: From Traditional to VR Delivery Method

In the last academic year, a transformation process towards the full digitalization of the IBDS course has started with the ultimate aim to fully apply Building Information Modeling (BIM) and immersive VR as a combined teaching and learning method. Inspired by the famous Dubai's City Walk, the students registered in this IBDS course were given a task to design a retail unit in a proposed site in Al Ain city. Each student was requested to select a function of the retail unit and develop a complete and integrated design for it. The design was expected to achieve functionality and constructability of the retail unit in a conceptually appealing manner while showing a high awareness of sustainability and environmental adaptability. The total built-up area of the retail unit was about 1000 m^2 on two floors.

As shown in Figure 2, the transformation process was conducted on multiple phases: Preparation Phase, Phase 1-BIM, Phase 2-VR, and Finalization-Presentation Phase. The Preparation Phase occupied 4 out of

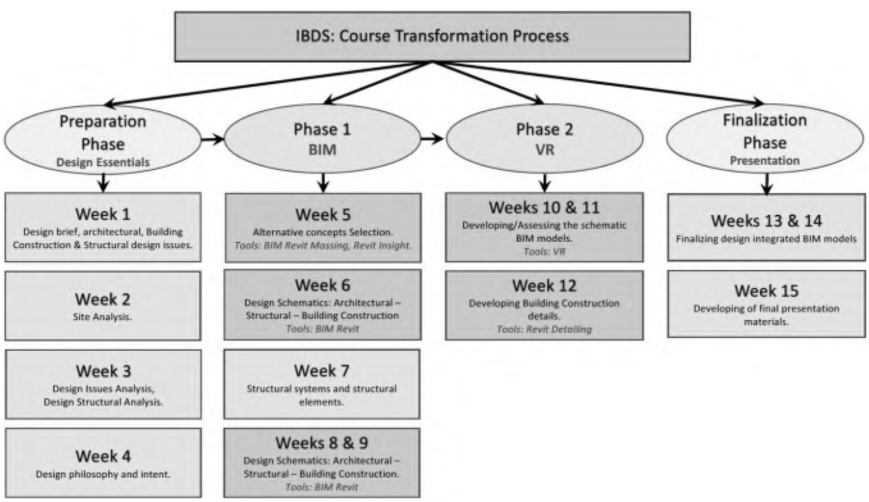


Figure 2. Intermediate building design studio course transformation process.

the 15 semester weeks in which the students undertook the preliminary studies and research about the various design issues of the building architecture and its building construction and structural systems, as well as its site analysis. The students figured out the suitable areas for the functional design spaces (showroom, storage, services, circulation, etc.) by reviewing some relevant case studies and design criteria. This Phase ended up with a clear definition of the design philosophy and intent of each student's project with its suitable construction and structural systems.

The following Phase 1 occupied 5 weeks and witnessed the full adoption of the BIM in the building design process, where the students were asked in week 5 to conceptualize their design ideas in three dimensions using BIM-Revit Massing instead of just sketching it on a plain paper, as used to be the case during the traditional delivery of the course. After developing at least two BIM conceptual model alternatives, students were asked to compare the prospected energy performance of these alternatives using Revit Insight. Then, during the following 4 weeks, the selected BIM conceptual model was gradually developed with the continuous feedback from the instructors and the jurors into a finally developed and rendered BIM model that integrates within its architectural form the building construction and the structural systems.

During this Phase, relying on BIM through Autodesk Revit was an essential pillar of the transformation process to help the students depict and comprehend all the building components and engineering systems as they will affect sustainability simulations of the building conducted through Revit Insight to guarantee that the design is achieving the CLOs of the course. Figures 3 and 4 below are for two examples of the students' designs that have a distinctive design and systems concepts, showing how the BIM modeling technique helped them to smoothly move from the conceptual to schematic and fully developed 3D model with all building systems elements easily investigated and corrected, if needed, using various inspection techniques such as Section Box and Walk-Throughs. The students navigated the model both internally and externally to identify the architectural design qualities, especially the spatial organization and form configurations, but still with no real sense of the actual scale of the building.

The developed BIM model, as shown on the student's laptop screen, is still not helping much in recognizing the architectural design qualities and the flaws of systems components and integration. Through integrating the VR as a teaching and learning design tool in Phase 2 that started at week 10 and ended up at week 12 (Figure 2) the students indeed managed to perceive their designs correctly because they 'jumped' inside their design spaces in real 'virtual' scale and hence recognized how suitable the spaces are in terms of size, organization, and form. Not only that, but also, they

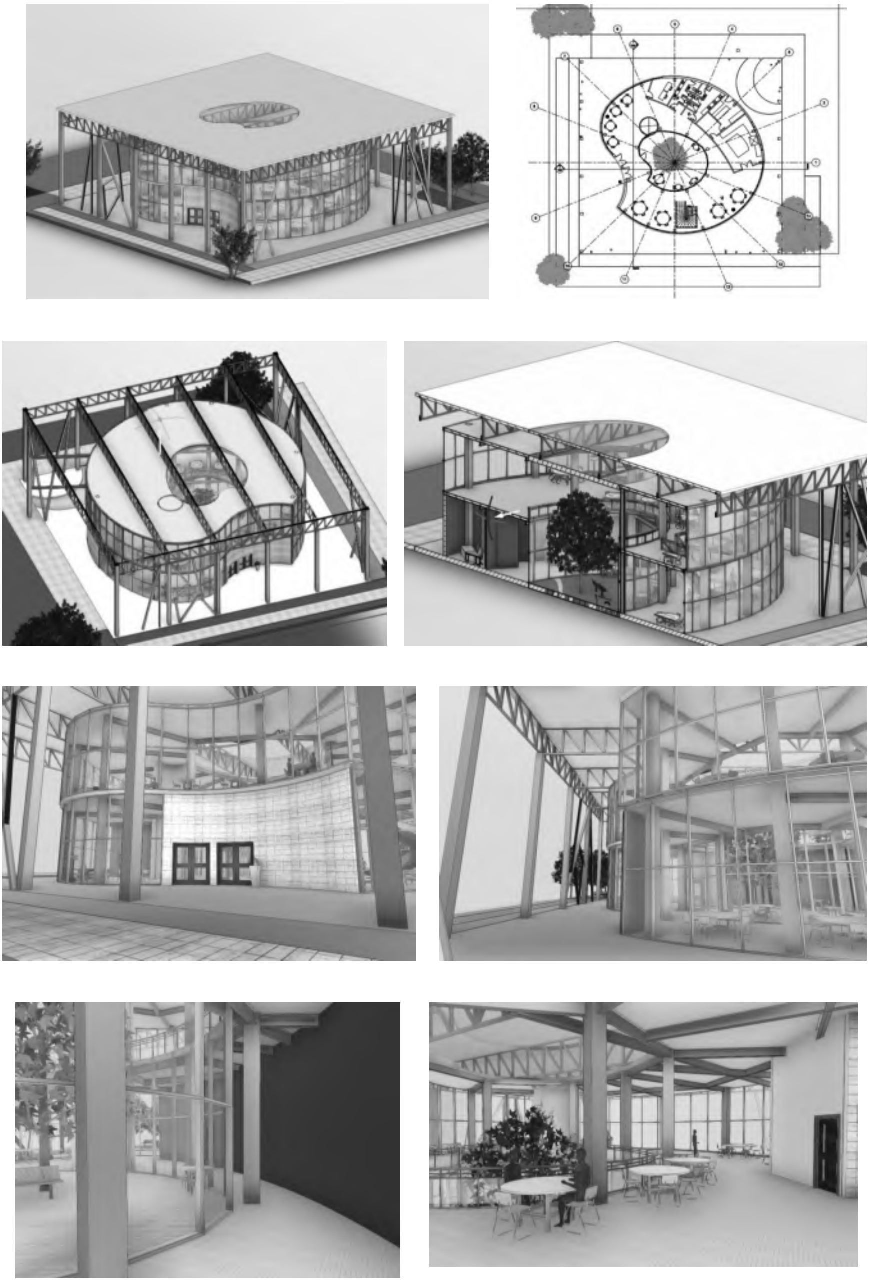


Figure 3. Example 1 of a student's building design fully developed using BIM on Autodesk Revit.

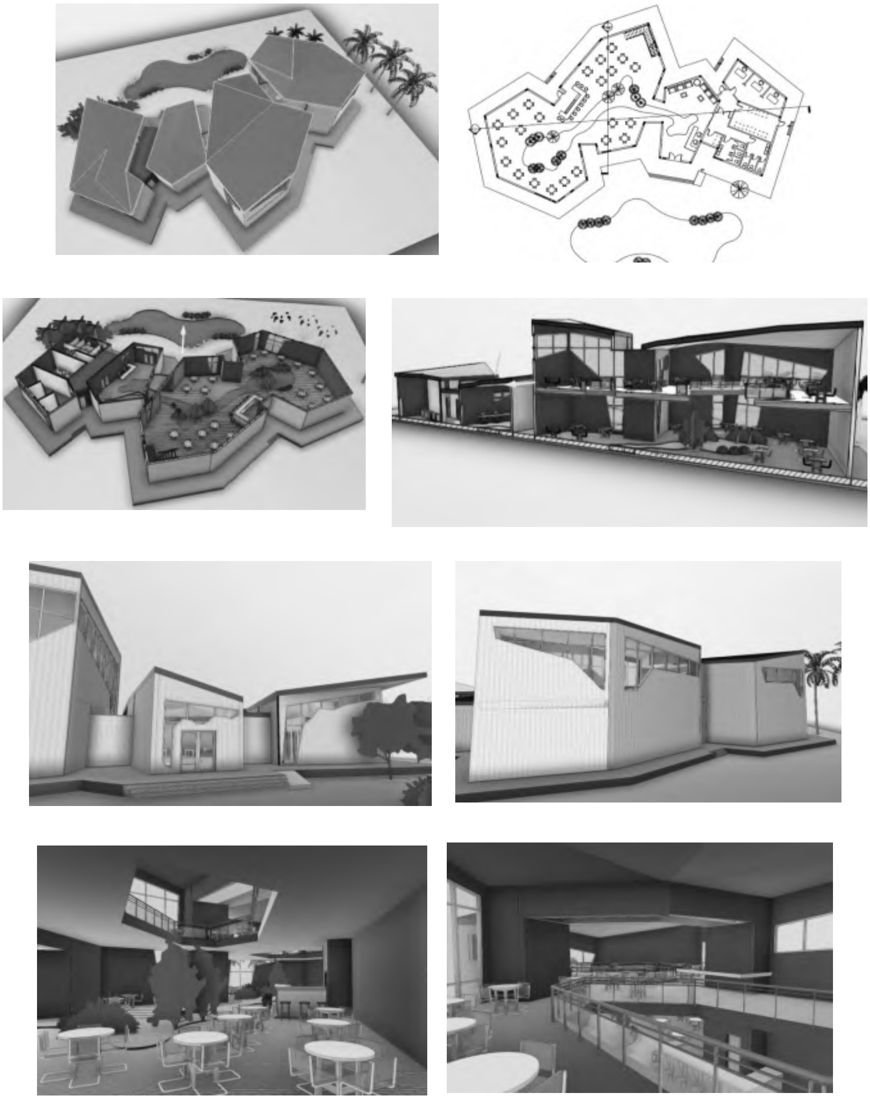


Figure 4. Example 2 of a student's building design fully developed using BIM on Autodesk Revit.

had the chance to hover over the building from outside either from a human eye perspective or a fly-over mode. To facilitate the process, an in-class mobile VR system (Gaming Laptop, Head Mounted Display (HMD), dedicated spatial tracking systems (Controllers), Revit and Enscape3d Plugin for Revit as the VR software) was briefly introduced to the students, and it was used in weeks 10 and 11. The VR display was also connected to the design studio's smartboard for engaging the instructor and other students in the feedback and comments on each other's projects. To facilitate the VR navigation process, the students were subsumed into two groups, each a group of 7 students. The 6 hours weekly class time were very tight as it was barely enough for the students to learn. Besides the tight time, some students needed more training on using the VR devices, and here the instructor's intervention was necessary.

Figures 5 and 6 below show some screenshots of the internal and external VR navigations for the two previously shown students' design examples (in Figures 3 and 4 above). Being immersive in a full scale virtual world, the students were really fascinated by the experience and managed to identify in such a 1:1 scale space, all the external form related qualified of their designs, as well as to internally perceive the spatial attributes of their design spaces. Utilizing the two modes of Walking and Flying, they were able to carefully investigate the different components of each system in the building, thanks to the detailed well-developed BIM models, as if they were riding a 'virtual' drone! In addition, they were able to clearly pinpoint the attributes of the building's construction and structural systems and recognize clash detection among them. The defined problems were recorded by a Research Assistant (RA) who helped taking screenshots for these spotted problems, as the students were busy navigating their projects. By week 11, the students managed to rectify the identified problems that would be considerably difficult to identify for such complicated forms without both techniques of BIM and VR.

Figure 5. Example 1 for the VR investigation of both outside form qualities and internal spatial and system integration qualities of the design shown in Figure 3.

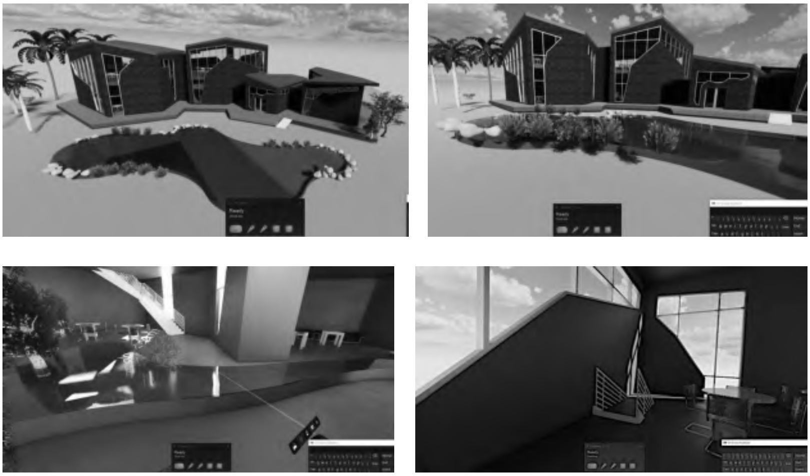


Figure 6. Example 2 for the VR investigation of both outside form qualities and internal spatial and system integration qualities of the design shown in Figure 4.

The three-weeks long finalization and presentation Phase starts at week 13. In this Phase, the students made any needed fine-tuning on their design projects and prepared the digital sheets and movies for the design drawings and rendering. The final presentation was done digitally without the need for any hardcopy printouts, and the jurors had the chance to use the VR handsets to navigate the students' designs. In conclusion, the transformation process of the IBDS has significantly contributed to the teaching and learning process concerning the overall building form, space size recognition in real 'virtual' scale, internal spatial qualities, and, more importantly, the integrated building construction and structural systems. The involved instructor's opinion for this phased transformation method as a teaching tool has been supportive of its effectiveness to better realize the CLOs and their related PLOs. The course instructor asserted that:

- The adopted method is advantageous in facilitating the feedback process as the students could easily recognize the design issues/problems when they perceive them on a real (virtual) scale.
- If compared to the traditional 2D/3D teaching tools, or even the BIM alone, the new method made teaching multiple systems and their integration very efficient when utilizing the VR over a developed BIM initiated design model. Therefore, the students were better engaged in the discussions about the raised issues.
- Still, the two VR sessions consumed more time than traditional teaching methods, where each student navigated his/her design space by space. With about 7 to 8 students at each VR session, more design

studio time would be essential. Alternatively, the time consumed in implementing the adopted phased transformation process could be shortened if the students were well-trained in advance on both BIM modeling techniques and VR tools during previous design studios and/or other dedicated classes/workshops.

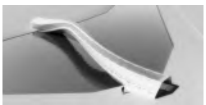
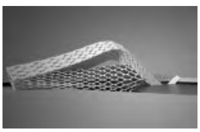
Meanwhile, the students' opinions about the applied transformation method as a learning technique have been very encouraging, as well. They affirmed the usefulness of the method as for them, it bridged a wide gap for their perception of various architectural, building construction, and structural components. The students asked for more training on using VR devices to be able to navigate correctly in their designs. They also preferred to have the chance for a self-paced VR experience in a dedicated VR lab, instead of only being able to use the system in the design studio.

3. A Journey of Parametric Architecture from Academia to Industry and the Connection to Virtual Reality

3.1 Case Studies and Applied Design in the Built Environment

The path of changing the concepts of design in architecture is a long process. It starts from the academic world where the ideas are always innovative and continues to the laboratories. Here there are trials in how the design can be applied to models. And on further development, it adapts to the industrial production and applies to real scale projects. In this section we are shown an overview of how the VR helps to connect the parametric design from an initial concept to sophisticated modelling, AI interaction, etc. New technologies have emerged and gained great interest in the field of architecture, engineering, and construction (AEC), including virtual reality (VR). The outstanding experience of the VR in the AEC field is mainly represented by the sense of presence, scale, and depth of the space. Mainly VR is used to help in communicating the design ideas and concepts to the stockholders, especially non-designers (Angulo 2015). For that, most architectural VR tools focus on the visualization and representation of the model, as a result there are mostly limited or no editing features provided in the tools (Gallas and Coppens 2019). In a workshop done at Tsinghua University about non-linear architecture parametric in 2010 there was an initial introduction in how this way of looking at architecture might change our build environment. The event was sponsored by Gehry technologies and involved 171 students who learned how to generate, parametrically control, and fabricate complex geometry. In Table 1 are shown some examples from 37 projects developed after this summer workshop (in contrast with Table 2, which shows applied parametric facades). Figure 7 shows the first 2D concepts of the parametric design. The 3 areas of focus were: software training, Advanced

Table 1. 3D examples of non-linear architecture workshop (ArchDaily 2020a).

3D Examples of Non-linear Architecture Parametric Workshop			
			
			
			

Parametric Design, and Fabrication. Part of the teaching process was to teach students how to achieve and visualize their projects and visions. Traditional architecture and visualization have already established a path. Meanwhile, the parametric architecture being very sophisticated in design and visualization still represents a challenge (ArchDaily 2020a). The Zaha Hadid Architects studio are pioneers in parametric design. In Figure 8 are shown pieces from 15 years of collective design research shown in a paradigmatic sequence of animation. Patrik Schimacher has shown this animation in lectures about parametric design, and Rosey Chan adapted her music to this abstract visualization. The video shows the movement from the simple linear shapes to complex buildings and urban districts. It's a symbolic way to show that parametric architecture can also be kinetic. The visual effects and the movement added in addition to the music show the complexity of this process that needs still more work to be visualized in its original form (Dezeen 2020). Meanwhile in Spring 2020 in the AI and Architecture Exhibition in Paris (virtual exhibition due to the pandemic situation) which is about generative design and machine learning, the main projects focus on: plans, elevations, structures, and perspectives in which AI could already contribute, whether real or speculative. This exhibition involved several researchers, industries, and disciplines. The tour of the exhibitions started from the studies on Modularity, Computer-aided Design (CAD), Parametric, and, finally, Artificial Intelligence (Figure 9). This is a showcase about the hybridization of practices. Concrete results from research laboratories and international operators were shown. Machine learning can now simplify parameters that previously

Table 2. Parametric design façades (ArchDaily 2020c).

Parametric Design Façades			
Ali Mohammed T. Al-Ghanim Clinic/AGi Architects	Ali Mohammed T. Al-Ganim Clinic/AGI Architects	Papagayo House/ Ariel Valenzuela + Diego Ledesma	Endesa Pavilion/Institute for Advanced Architecture of Catalonia (IAAC)
			
Vadeggio-Cassarate Gallery/Cino Zucchi Architetti	LanQiao Clubhouse/ HHD_FUN Architects	Louverwall/AND	Maslak No.1 Office Tower/EAA - Emre Arolat Architecture
			
Hospital Manta/PMMT	Public Bathroom/ HHD_FUN Architects	Malta Maritime Trade Centre/AP Valletta	30 St Mary Axe Tower/ Foster + Partners
			

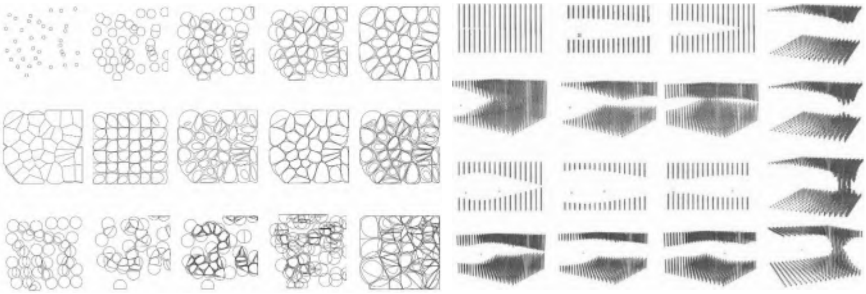


Figure 7. Examples of non-linear architecture workshop, 2D concepts (Dezeen 2020).

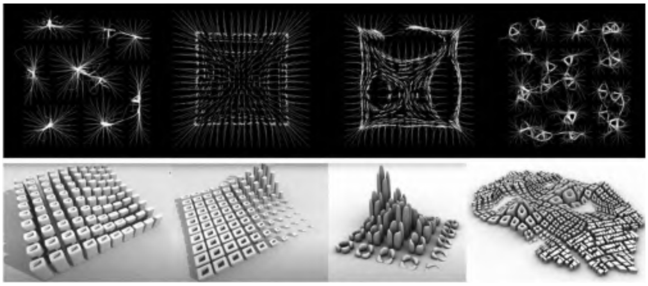


Figure 8. Parametric design concepts liked with music, from Patrik Schimacher and Rosey Chan (ArchDaily 2020b).

Figure 9. Exhibition of the AI Parametric design in Pavilion l'Arsenal in Paris, France (ArchDaily 2020c).

were considered too complicated. It is a learning process for the parties involved. This virtual connection of how sophisticated design can be simplified and shown accordingly is a significant step ahead to the longer process of the AI technology and architecture (ArchDaily 2020b).

VR can be used to enhance the design and visualization experience of the architectural parametric models. Using the VR interfaces, designers can have a visual analysis of complex parametric building designs from a human-scale perspective, as it allows multiple views and body-centered building navigation. Besides, combining numerical evaluators, like the building performance simulation tools, adjustments in the design process, can be directly connected to performance results in a significant interactive qualitative-quantitative platform (Caldas and Keshavarzi 2019). However, editing the parametric model in the VR environment is still under-development. One of the limited tools that is capable of streaming the architectural geometry from Grasshopper (parametric modeling tool) to VR was studied and discussed by (Gallas and Coppens 2019, Coppens et al. 2020). The work performed helps the designer to adjust the parametric values inside the VR environment, allowing the graph-based model to be fully edited (users can add, delete or move geometries). The changes done to the design could be restored to the Grasshopper original file. This means that an architect can interact with the parameter values of the parametric model within the VR context and find out what would be the end outcome on the geometry.

As the parametric design also evolves the tools that can apply this into reality are advancing. Table 2 shows an application of the idea of cities and buildings based innovation, optimization, improving performance, and monitoring maintenance. The 3D printing tools have given the possibility to pass from the virtual dimensions of the parametric design to the repetition of the pattern that is a part of a movable architecture with the aim of optimization and high building performance. This new application shows that the innovative way of thinking can be applied in reality. It creates new concepts of design, space, material composition (ArchDaily 2020c).

3.2 *From Design to 3D Printing, the VR Contribution to Applied Projects*

VR design tools can be very practical and useful in the design processes. It helps architects and engineers enhance and evaluate their design and decision-making workflow by feeling present within the building. A study done by Witmer and Singer (1998) conducted a 'presence' questionnaire, which had an argument about a possible relationship between the presence and the task performance in the VR environment. Similar questionnaires in the AEC field have been conducted by several studies (Castronovo et al. 2013, Kalisperis et al. 2006, Faas et al. 2014). Other than the individual design process, conducting a virtual collaboration in a building project among different stakeholders is a significant factor that can influence several phases of the design procedures (Cladas and Keshavarzi 2019). The most common VR softwares are Unity Reflect, Autodesk Revit Live and Iris VR that enable building walkthroughs and immersive visualizations. Sketching in the early design phases is another VR promising application that needs to be developed. Currently, there is no sketching tool specially designed for architects. One of the available sketching tools is the 'Googke

Tilt Brush,' which allows the user to draft a freehand drawing in 3D space while physically roaming around the sketch (Google n.d.).

For the building performance field, different VR tools were found to be used in visualizing previously simulated values or performing accurate live simulation in a VR environment. A daylighting analysis and simulations VR tool called 'RadVR' is specialized in integrating the Radiance raytracing quasi-real-time quantitative calculations with renderings. RadVR gives the flexibility to the user to move the sun through its yearly solar path, within the VR environment, which can be used for solar radiation studies as well as for performing specific day and time illuminance calculations (Keshavarzi et al. 2019). On the other hand, some researchers focused on introducing VR energy simulation tools. Nytsch-Geusen et al. have used two-way data sharing between VR game engines and Modelica (an existing energy simulation tool); to implement a VR energy simulation environment (Nytsch-Geusen et al. 2017).

Similarly, the 'EnergyVR' was developed by Tafrihi and Caldas in 2018, which is a prototype tool that performs the EnergyPlus simulations in the VR environment. The EnergyVR is capable of representing real-time updates of the model in the VR environment, which can help the designer understand the impact of the applied changes of the different design choices on energy consumption (Tafrihi et al. 2018). Other researches used the VR for performance-based design as an end-user tool and the occupant input method. These methodologies were investigated in designing openings and building facades to assess daylighting preferences for end-users.

The VR technology, along with other new technology, has initiated the construction evolution, a further step could also be a new massive-scale manufacturing technology with 3D printing (Furet et al. 2019). Such technologies help make sure that construction techniques are overdetermined and support the integration of different technology advances done within time, cost, accessibility, sustainability, thermal and visual comfort, buildability, and maintainability into a systematic decision-making tool. For that, technologies can play an essential role in speeding up and enhancing different construction processes, so that both academia and industry are involved in implementing and adapting technologies in the research and construction projects (Cho et al. 2019). One of these technologies is 3D printing, which is a method that produces a layer by layer of physical objects by inserting material according to a digital model. The interaction between it and the VR was found to be effective in supporting the design changes and reducing the time of the redesign and reprinting. The model components done using 3D printing will have to be tested individually as well as in the assembly process. Therefore, VR is a powerful tool for 3D printing, as it allows for the simulation of the whole model and thus can spot possible issues before the actual printing takes place. The integration among VR and 3D printing brings new prospects for the construction industry. Since VR helps to provide an integrated 3D model, it could be used from a 3D perspective to validate potential, and alternative 3D printed designs (Lee et al. 2019).

Recently, 3D printing technology has been applied to the construction industry. The main benefits of 3D printing to the construction industry are:

- Shorter construction time mainly compared to traditional construction.
- Utilizes the quantity of materials and, consequently, less building waste (Bak 2003).
- Increases architects' creativity thanks to the ability and freedom to create complex shapes, complex forms monitored cost.
- Reduction in the overall human labor, mitigation of strenuous work, and preparation for the environment, thus reducing the risk of accidents and costs at work (Buswell et al. 2003).
- Optimization of the building's acoustic or thermal properties.
- The whole digital process, first from drawing of the building to the construction, is completely integrated: from the design of the plans on a computer to the manufacture by the robot; this allows the design of the building to be digitally checked such that the robot produces the correct shapes instantly (Lee et al. 2019).

A research carried out by Furet and others has introduced a different methodology called Batiprint3DTM, a new 3D printing method for buildings used to produce a triple wall of 3D printed materials. A subsequent wall made of concrete cast by a robotic 3D printer is enclosed with two polymer-foam printed walls. It has been tested with a real 95m2 social housing in Nantes (France). It is fully finished and has been occupied by a family since June 2018, and its use is highly valued by its occupants in terms of comfort and pleasure (Furet et al. 2019).

Another case is the gardens of Andy Rudenko, which was printed using contour crafting. The representative example of using an open-source project technology and software called RepRap 3D print. The printer's used materials was a cement and sand mixture. The whole building was printed in one cycle, excluding the top towers that were printed and then installed on the building (Lee et al. 2019, Hager et al. 2006).

One of the exciting 3d printing projects was designed by the Austrian architect Wolf D Prix that used the robots in the Museum of Contemporary Art and Planning Exhibition (MOCAPE) in Shenzhen, China (shown in "'Robotic construction is the future' says Wolf D Prix." [Online]. Available: https://www.dezeen.com/2015/10/23/robotic-construction-

3d-printing-future-wolf-d-prix-interview/ [Accessed: 23-Aug-2020]). It consists of an irregular model that was assembled, welded and polished stainless steel and metal plates based on BIM system. Prix illustrated that the use of 3D printing in building components could make the building complex shapes a lot easier.

The digital fabrication is an innovative concept of 3d printing that is based on parametric design. The VR technology could possibly interact with the application of the units into the structure. The Galaxia, is a project that represents the city of the future. A symbolic structure is based on 3D printed units connected in a rotating structure. This project also shows a natural approach to materials and how the materials express themselves. Meanwhile, Conifera is another project presented in Milan Design Week and is made from materials of renewable resources. Both projects are developed from architect Arthur Mamou-Mani (Figures 10 and 11) (ArchDaily 2020d,e,f).

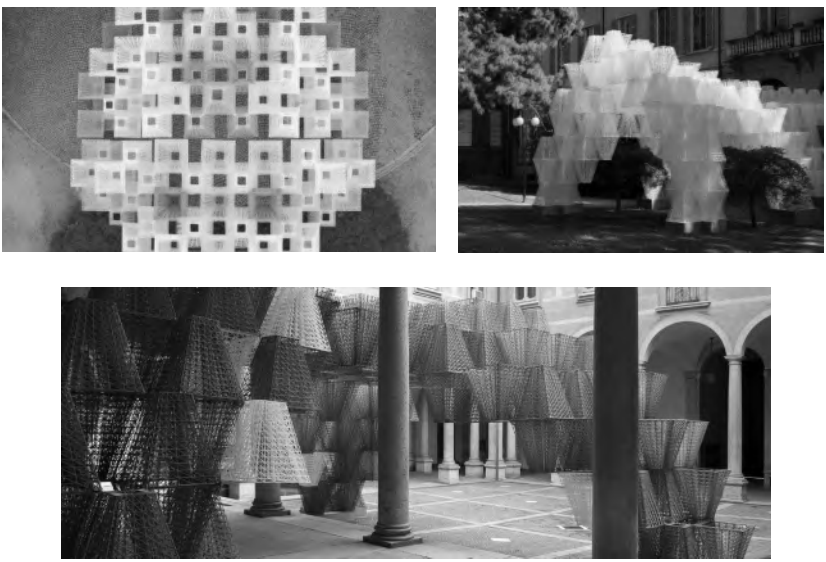


Figure 10. Images from Conifera Project (ArchDaily 2020f).

3.3 Reflections and Future Applications Possibilities of the VR in the Parametric Architecture, Digital Fabrication 3D Printing. AI Contribution into Discipline Hybridization

In this section, there was an overview of the Parametric architecture from the design phase to the execution phase. The literature review shows that the application of VR in the early stages of design speeds the decision making as it makes the projects more understandable to the large public and not only to the professionals in the construction world. Since the

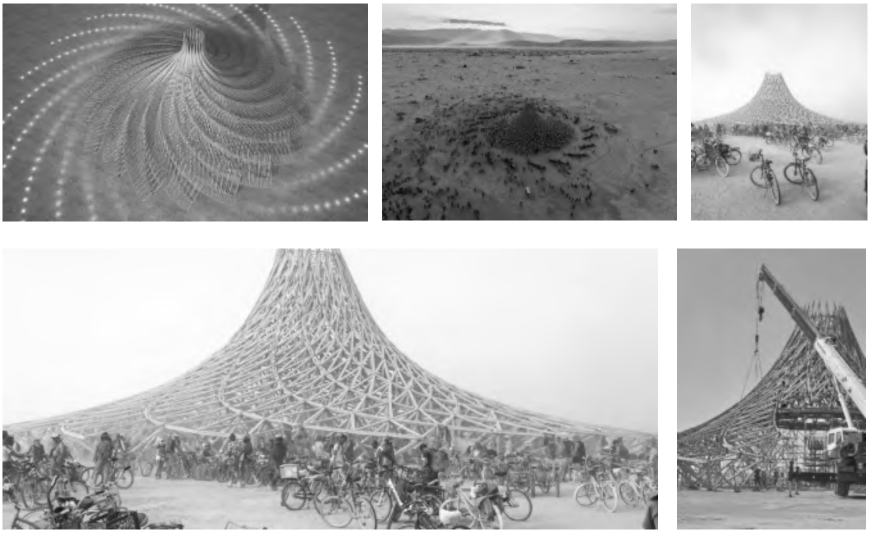


Figure 11. Images from Galaxia Project (SAS Reporter, Gulf News n.d.).

parametric Architecture is currently evolving faster due to the available tools, this leaves more space for the VR to adapt to this technology. Optimization of facades includes interactive elements that have an impact not only on the building performance but also on the exterior and interior of a certain structure (building or district). For the decision-makers to be able to see this connection between the energy benefits but also from the visual benefits before the project takes life is an achievement.

However, there is space for improvement in the current tools in terms of connection to the VR in each step of the design and then execution. The 3D printing technology and digital fabrication are strictly connected to the initial phases of the design. The stability of the structures due to the use of innovative materials is still a learning process. Since we are at the beginning of this transformative way of building, the VR adaptation to how the parametric structures can be printed and built would help the construction industry to make more trials in materials and stability of different typologies of buildings. This would allow the use of recycled and innovative materials in affordable buildings.

Moreover, AI and machine learning are now part of the process of decision making in architecture. The use of reliable computing of calculations and geometries previously thought as too complicated, gives an opportunity to explore more the different disciplines and connect them. The research laboratories, the technology companies, the construction companies connected can improve the time and cost of construction. Trials in laboratories and architectural exhibitions are avatars of such an innovative approach to this dynamic. Machine learning based on available data can give the best available scenarios of specific structures (buildings) in terms of design, performance, stability, application to reality. The parametric design, 3D Printing, Digital Fabrication, innovative materials are all variables in a hybrid connection to the AI. VR is the face of such technology that shows the results of all the elaboraten work done in the background of each project.

4. Applications of VR in Civil Engineering

The construction sector in the whole world, including the United Arab Emirates (UAE), has recently come under substantial pressure due to the coronavirus pandemic and the slump in oil prices; however, it remains resilient with its planned projects ready to resume. The federal government of the UAE invests every year in new facilities to improve their domestic infrastructure. According to an article published by Gulf News (SAS Reporter Gulf News 2014). The UAE government is expected to spend over $300 billion by 2030 on infrastructure development. The country has a pipeline of $5.4 billion of federal infrastructure projects for the year 2020 (ENA n.d.). Local municipalities and contractors in UAE are facing massive tasks to monitor ongoing projects, maintain existing facilities, and repair existing and install new infrastructure utilities. In general, theses may include inspecting on-site activities of projects and monitoring their progress and installing, replacing, and repairing main water pipelines, telecommunication networks, power lines, and stormwater and sewage pipelines. The majority of these tasks are mainly associated with underground utilities that utilize different technologies to install or maintain, primarily using traditional open trenches. These open-trench operations are quite expensive, particularly in large congested metropolitan cities where contractors are used to digging cautiously and have to maneuver around existing utilities to achieve the target work depth that usually causes slowing down the operational process.

Moreover, restoring existing structures, pavements, sidewalks, and landscaping results in additional costs. High user costs (known as social costs) are caused by open-cut trenching operations as a result of the disruption to traffic and the negative consequences on the businesses around (Zayed and Mahmoud 2013). Open trenches can also result in environmental impacts or damages to existing infrastructure (Yan et al. 2018). Trenchless technology methods, adopted mainly to replace and repair underground infrastructure utilities, have attracted more attention by contractors and municipalities as an alternative technique to be used to reduce the cost of replacing or repairing aging services (Al Khatib and Ahmed 2020). Despite the importance of using trenchless technology methods for the installation and rehabilitation of existing underground utilities, the use of these technologies is proved to be expensive and may lead to unexpected additional costs.

The use of Virtual Reality (VR) and Augmented Reality (AR) has experienced a breakthrough in many areas of civil engineering applications due to cheaper hardware and a strong industry commitment. In this part of the chapter, the applications of VR and AR in civil engineering are highlighted, and a summary of the benefits of using these technologies in civil engineering, including underground utilities, is then presented. This includes their use to arrange virtual site visits, collaborate with various project parties, check the status and progress of construction projects, and monitor and review on-site construction activities. Other useful applications include locating, visualizing, interacting, and navigating the different elements of underground utilities to evaluate their functionality and existing conditions and decide whether any maintenance or rehabilitation work is needed. Some of the challenges and limitations associated with the use of VR and AR and potential future trends are finally presented. The use of such technologies is expected to help engineers, municipalities, and contractors in UAE have a better decision-making tool for managing their projects and maintaining or replacing underground utilities more efficiently with less cost and minimum social disruption.

Using VR and AR, spatial data can be visualized in an intuitive and interactive way. This helps to conceptualize the details in the spaces around the components of buildings and utilities. As such, accurate planning can be done effectively and efficiently. VR and AR simulate real-world projects so that engineers can have an insight into these projects. The process starts with a 3D model used in a VR environment before the commencement of construction. The applications of VR and AR in civil engineering is relatively new compared to their applications in other fields such as manufacturing, gaming, military, and medical operations. The following subsections focus on and summarize the applications of VR and AR, mainly in construction and underground utilities.

4.1 Applications in Construction

Researchers have identified various beneficial capabilities for using VR and AR in the construction industry. This includes checking the status of projects by comparing the as-built with the as-planned status, conducting virtual construction site visits, enhancing collaboration among various parties during the design and construction stages, planning new projects, and training for similar projects based on the lessons learned from previous projects. Rankohi and Waugh (2013) presented an in-depth literature review of the use of AR technologies in construction during the period from 1999 to 2012 to synthesize the trends of AR technologies for construction projects and identify key application areas. According to their study, the AR literature has focused on the visualization and simulation applications related to monitoring construction progress. At the same time, there is a need to make further developments in using web-based mobile augmented systems for monitoring on-site construction activities. This has drawn the attention of other researchers to explore other areas of possible applications of VR and AR in the field of civil engineering.

In an early research attempt, Webster et al. 1996 developed an AR system to improve the inspection and renovation of structures by allowing users to see columns behind a finished wall and re-bars inside columns. In another study, Roberts et al. 2002 presented an attempt to integrate AR and GPS for subsurface data visualization by superimposing virtual images onto a real-world view. Behzadan and Kamat (2007) designed a mobile AR framework to visualize simulated construction operations for the purpose of validating the results generated by discrete event simulation. A tool to check discrepancies was developed by Georgel et al. (2007) to readily obtain an augmentation in order to find the differences between an as-designed 3D model and an as-built facility. Behzadan (2008), on the other hand, listed several applications of AR technology in civil engineering and construction. Examples of significant AR developments and applications include visualizing underground utilities, providing the ability to look beneath the ground, and inspecting subsurface utilities. The use of AR has been extended to excavation safety and subsurface utilities by improving visual perception, where AR can serve as a useful inspection tool (Behzadan and Kamat 2009, Schall et al. 2010). Golparvar-Fard et al. (2009) focused on using AR to visualize performance metrics to measure progress deviations through the superimposition of 4D as-planned models over time-lapsed photographs of real construction sites. Dai et al. (2011) presented a system to overlay as-built drawings onto site photos for quality control monitoring. Rankohi and Waugh (2013) conducted a statistical review of research studies related to the use of AR in construction projects and potential future trends in this area. Their study showed that workers and construction project managers have a high interest in using AR technologies during the project's construction phase, mainly to monitor progress and detect defective work. Other research efforts focused on the use of AR for viewing complex assembly models on mobile phones (Woodward et al. 2012), improving remote design review collaboration (Siltane et al. 2013, Wang and Dunston 2013), visualizing computer-generated models collaboratively (Dong et al. 2013), analyzing, visualizing, and assessing construction progress with unordered photo collections and 3D building models (Karsch et al. 2014), and delivering visual project information to students and trainees to enhance learning (Shirazi and Behzadan 2014). As reported by Behzadan et al. (2015) and

Fenais et al. (2018b), the University of Michigan developed a laboratory for interactive visualization in engineering. This laboratory is used to facilitate AR research with applications related to construction operations, planning, inspection, safety, and education. The developed visualization system also helps excavators to avoid collisions by allowing excavator operators to see buried utilities.

More recently, Behzadan et al. (2015) investigated the fundamental challenges that prevent the AR technology from being deployed in more civil engineering applications. Some of these challenges are shown under the "Limitations and Challenges" section. Hilfert and König (2016) presented a way to build a low-cost AR environment for civil engineering and construction applications. Algohary (2015) and Agarwal (2016) presented the benefits of using AR in civil engineering applications to reduce or instead eliminate errors that appear during construction and discussed the use of AR to recreate drawings in actual scale on the field by creating a 3D image. Their research also discussed the importance of using AR to efficiently monitor work progress, improve quality, and reduce the overall cost of construction projects. Erkoyuncu et al. 2017 developed an adaptive AR procedure to automate the geographical positioning and specific content definition to improve the efficiency of maintenance tasks by reducing their completion time and errors and, therefore, increasing maintenance efficiency. In another study, Oesterreich and Teuteberg 2018 proposed an approach that combines the method of utility effect chains and system dynamics to develop a quantification model for specific AR applications. Chu et al. 2018 evaluated the effectiveness of integrating AR with BIM to enhance task efficiency through improving the information retrieval process during construction. Recent applications of AR have helped in improving the performance in different areas of civil engineering and construction.

4.2 Applications in Underground Utilities

The growth of urban underground space is increasing significantly in the world's largest cities. In the United States, for example, there are over 35 million miles of buried services, and this number is growing every year (Fenais et al. 2019). Researchers have been using AR and VR to visualize underground utilities, and the construction industry will continue to adopt the AR and VR technology in the future to provide the ability to look beneath the ground for subsurface utility inspection (Fenais et al. 2018a). Several publications have been made in the last few years to investigate the use of AR and VR technologies to view underground utilities for either monitoring or collision avoidance. This is generated by applications and devices developed to improve the accuracy, usability, and reliability of the technology. This part investigates the applications of AR and VR to visualize and examine the existing conditions of underground utilities.

AR has been identified as a technique that could enhance the information extraction of underground utilities from the virtual world to the real world and improve the access and utilization of such information (Fenais et al. 2019). However, applying such technologies for underground utilities requires accurate and up-to-date information. This has been thoroughly studied by Dutta et al. 2013, Muggleton et al. 2011, and Royal et al. 2011 to provide improvements over previous studies. Schall et al. 2009, for example, presented an AR system for aiding field workers in maintenance, planning, and surveying tasks of underground utilities. In a similar study, Schall et al. 2012 presented a mobile AR system that can be used for the interactive visualization of hidden underground utilities. Dong and Kamat (2013) developed a framework for visualizing civil infrastructure systems using AR, including the visualization of underground utilities for excavator control and collision avoidance. Thompson (2015) developed a system for locating and verifying the position of underground utilizes using VR by generating a 3D model in a virtual space and displaying an image of the model, which allows an excavation probe operator to position and guide the probe to intersect and verify the existing utility. Stylianidis et al. (2016) presented a system called "LARA" to integrate AR with the European Global Navigation Satellite Systems (GNSS), 3D geographic information system (GIS), and geodatabases on a mobile platform for monitoring, documenting, and managing underground utilities on-site. Using the "LARA" mobile device, AR and 3D GIS geodatabases aids users in seeing beneath the ground by rendering the 3D utilities' models. The visualization of underground utilities is made using a mixed reality paradigm, where the user can see the utilities and the surroundings at the same time rendered at their exact location in 3D (Stylianidis et al. 2020).

More recently, Jurado et al. 2018 developed a 3D environment that provides real-time interaction, visualization, and management of underground utilities using virtual reality. Soria et al. 2018 presented an approach to use AR for life-cycle management of subsoil infrastructures, including visualization, interaction, and free navigation, in addition to editing, deleting, and inserting elements ubiquitously. Fenais et al. 2018b identified and discussed the various challenges of applying AR in the underground utility construction industry through a review of over 500 publications from 2006 to present and a Meta-analysis of the data. In this research, the challenges and barriers were categorized, and recommendations to overcome these challenges were presented. Some of these challenges and barriers are listed under the "Limitations and Challenges" section. In another study, Fenais et al. 2018a discussed the use of AR for trenchless technology (TT) projects and how the application of AR with horizontal directional drilling (HDD) can reduce risk significantly. Bergquist and Stenbeck 2018 developed an AR tool for the recognition of vertical underground surfaces and found that the developed AR tool does not provide the same precision as manual measurements but is considered reasonably acceptable. Fenais et al. 2019 have indicated that most AR applications and research have focused on registration performance, without reporting on the input data accuracy. The work of Fenais et al. 2019 focused on the development of an exciting system to integrate AR and GIS for mapping and capturing underground utilities using a mobile device. The data can then be instantly accessed in the field to enhance information retrieval, improve worker safety, and reduce pipe-striking incidents. Kaddioui et al. 2019 summarized the types of AR and discussed how this technology could help in underground utilities repairing and maintenance. The study of Kaddioui et al. 2019 presented a mobile location-based AR system using smart device sensors and real time kinematic satellite navigation technology for improving the accuracy of the locations of underground utilities. This system enables GIS data visualization to help field workers in the maintenance operations of underground utilities.

The following section summarizes some of the significant benefits of using AR in civil engineering and construction.

4.3 Summary of the Benefits of Using VR and AR in the Civil Engineering Domain

In essence, using VR and AR reinforces the connection between individuals and objects, increases the awareness of engineers while performing field tasks, and reduces the cost of 3D models by using real-world background layers (Behzadan et al. 2015, Fenais et al. 2018b). Besides, using VR and AR technologies allows construction managers and engineers to:

1. Visit construction sites virtually by walking through these sites while viewing an augmented overlay of a BIM model on top of the as-built construction
2. Take pictures or videos for review by the project team
3. Visualize underground utilities such as pipes, cables, and ducts for waterlines, drainage systems, telephone lines, electric cables, etc. Mapping and capturing existing underground utilities help in locating these utilities to avoid or significantly reduce the risk of striking an existing underground utility and, therefore, potential damages and costly litigations can be significantly reduced

4. Manage, examine, and evaluate the functionality and existing conditions of underground utilities to see if any maintenance or rehabilitation is needed. This saves the cost of digging open trenches or using costly trenchless technology methods
5. Document and review construction documents on a real scale. This helps in quickly identifying small errors and problem areas that might have been overlooked during design
6. Check the status and progress of construction projects
7. Continuously monitor and review construction activities to ensure that construction adheres to approved documents. This prevents possible errors and eliminates the time and efforts required to rectify such errors during construction and, therefore, saves time and money
8. Explain construction projects to owners and potential customers by presenting virtual tours for clients, which serves as an exceptional marketing strategy
9. Have a printed QR code to synchronize the location of digital 3D data with the real world. Engineers could walk around the objects as if it is there in real life
10. Collaborate effectively with the various project parties during the design and construction stages of projects
11. Plan new projects
12. Conduct training sessions for similar projects based on lessons learned from previous projects

4.4 Limitations and Challenges

Despite the importance of previous efforts related to the use of VR and AR in civil engineering applications, current VR and AR use focused mainly on the visualization and simulation applications related to monitoring construction progress. As such, these applications are mostly for presenting data that have been prepared by specialized software but have no capability to edit or add data dynamically on-site (Cote and Mercier 2018, Chi et al. 2013). On the other hand, the American Society of Civil Engineering has identified 17 challenges in the visualization, information modeling, and simulation of civil engineering projects (Leite et al. 2016). Although VR and AR have addressed some of these challenges, particularly those related to visualization, these technologies have not been fully adapted for use in civil engineering due to some limitations preventing the development of practical applications (Fenais et al. 2018b, Golparvar et al. 2013). Some significant limitations associated with the use of these technologies in civil engineering applications are summarized as follows:

1. Modeling information and alignment barriers and accurate positioning. This includes the alignment of virtual objects with the real-life environment across time and space and considering the weather conditions and obstacles such as existing buildings and structures
2. Integrating VR and AR to a scalable and extensible computing framework that is openly accessible to the construction industry and the teaching and research communities
3. Storing, managing, and processing a massive amount of project data.
4. Updating visualization in real-time for dynamic environments of construction projects
5. Tracking the exact and accurate locations of underground utilities
6. Issues related to data collection and the required high accuracy of data
7. Hardware limitations

4.5 Potential Future Trends

The literature in VR and AR has focused on the visualization and simulation applications related to civil engineering projects and monitoring construction progress while the future trend is expected to be in the following aspects:

1. Effectively maintaining underground utilities. This is still a challenge due to the complex data structure and the difficulties associated with their direct inspection. This includes the accurate positioning of the locations of defects in underground utilities and providing accurate photos of these defects for possible repair and maintenance
2. Using web-based mobile systems for monitoring on-site construction activities
3. Addressing practical challenges related to mobile field implementation, such as:
   - Mobility and ergonomics requirements (i.e., user comfort)
   - Power limitations
   - Ruggedness (ability to function in hectic and harsh environments)
   - Robust image registration for uncontrolled outdoor conditions (i.e., synchronizing the captured image and sensor measurements)

- Filtering ambient noise and data interferences
- Adding more interactivity features (e.g., providing the user with the ability to connect to a remote server and update project information and progress status in real-time)

4. Integrating VR and AR efficiently with GIS systems
5. Measuring the productivity and performance of engineers and labors in construction projects
6. Improving logistics and maintenance in construction and enhance workers' training
7. Applications with TT or as a replacement to TT
8. Continuous increment of 3D underground representation to support 4D analysis and, thus, predicting the future needs for smart cities maintenance

4.6 Reflections and Remarks

With the current market pressure and high competition, civil engineering companies and contractors continue to look for more effective and less costly ways to streamline their operations, and VR and AR seem to be the technologies that will address these issues. VR and AR have significant benefits for civil engineering and construction companies, and these technologies are becoming more popular and easy to acquire in terms of the required hardware and software and the associated cost. Among these benefits in the civil engineering, domain are conducting virtual site visits, collaborating with various project parties, checking the status and progress of construction projects, and monitoring and reviewing on-site construction activities. Other useful applications include locating, visualizing, interacting, and navigating the different elements of underground utilities to evaluate their existing conditions and decide whether a repair or replacement is needed. However, there are still some challenges and limitations associated with using VR and AR such as modeling information, modeling alignment barriers, accurate positioning, integrating VR/AR with scalable and extensible computing framework that is accessible to the construction industry and teaching and research communities. Other issues that need to be addressed include data collection and the required high level accuracy of data, hardware limitations, updating visualization in real-time for dynamic environments of construction projects, tracking the exact and accurate locations of underground utilities, and storing, managing, and processing large amount of project data.

Some possible future research directions and trends were highlighted in areas related to accurate positioning of the locations of defects in underground utilities, web-based mobile systems for monitoring on-site construction activities, efficient integration with GIS systems, and measuring the productivity performance of construction personnel. It is also crucial that future research efforts address the practical challenges related to mobile field implementation. The use of VR and AR technologies is expected to help municipalities, engineers, and contractors have a better decision-making tool for managing projects and maintaining or replacing underground utilities with less cost and minimum social disruption. These technologies will also help civil engineering and construction firms become more competitive locally and globally.

5. VR and the HVAC Systems

Virtual and augmented reality has many advantages that could contribute positivity on the constructional field, the technology could be used for visualizing the complete design of the site or the building be the team to detect the possible clashes that may exist to find fast and practical solutions, and this would be helpful to the contractors together with the designers to figure out virtually how the site will look like while constructing the building. Moreover, the technology can provide an accurate alignment of holographic information. So for the real world, this can be combined with the digital models where accurately the contractors can demonstrate how the designed infrastructure, like HVAC, utilities, ducting system, will be interacted with the existing infrastructure, especially for maintenance and development. It has been focused on using augmented reality technology in the service field, where technicians perform many maintenance tasks in a shorter time. The augmented reality system headset can be used by the technician who could receive step-by-step instructions that guide them through the repair of the HVAC system (IOT World 2020). Besides, the assembly process is essential in many industries like construction, where a wide range of mechanical parts can be used to assemble the mechanical system such as Heating Ventilation Air Condition and piping assembly (Hou and Wang 2013). Augmented reality can be used effectively for training is more effective for novice assemblers who undergo considerable cognitive workload. HVAC systems are responsible for a significant share of industrial energy consumption and the overall energy efficiency and air quality. Different ventilation and operation scenarios for HVAC can be examined in learning scenarios and training by using a mixed reality system that provides three-dimensional visualization of the cyber-model and computed results for the learners. With analyzing and understanding the indoor air conditions, this enables future engineers and experts to design and set them up in a way that improves human comfort while reducing energy consumption (Czarski et al. 2020). An innovative analytic approach using virtual reality technology was developed to help to build designers to identify the design pattern which guides the occupants to behave in the most energy-efficient way, in order to close the energy performance gap resulting from occupants' misconduct (Niu et al. 2015), where a VR assisted innovative occupant-engaged framework in building energy design based on design with the Intent method. A new AR-based methodology was developed for intuitively visualizing indoor thermal environment for building renovation projects, where the system is easy-to-comprehend visualization of CFD results augment the real scenes to provide users with information about the thermal effects of their renovation design alternatives interactively (Fukuda et al. 2019). The design process using the proposed system enables the comparison of CFD results. The user can analyze the CFD results that are visualized in the AR environment along with the building features and discuss changing the configurations of the building and HVAC components. When a facility is constructed, there will be large amounts of design and as-built information in a wide range of specialty services such as HVAC, mechanical, electrical, structural. Usually, information is represented and stored as 2D plots rather than 3D models in practice. It apparently exists a lack of well-structured integrated 3D databases, which could be readily used by AR systems to support information source extraction (Wang 2009). A computational support system was developed to reduce the inefficiency factors due to difficulties with accessing information and data in operation and maintenance support systems and tested to show potential improvement in equipment operation and maintenance fieldwork efficiency with the computational support system. A focus on building HVAC systems, especially three-dimensional elements such as pipes, ducts, and valves (Researchgate 2020) to improve efficiency at the site and the experimental evaluation of the application. VR allows users to create an entirely new reality that fully immerses the participant into that environment. By using a headset and controllers, users can predict how components fit together, determine if there is enough space, and learn the basics of how to design, build, and install an HVAC system without real-world consequences (ACHR News 2020). Moreover, the industry will be teaching new engineers about how to install a system without leaving a classroom and showing clients the airflow throughout each room in their building, as well as how the air distribution system is interconnected to the entire HVAC system. A new independent concept used to classify the spectrum of reality technologies, as referenced in the reality virtuality continuum, is MR of Mixed Reality. As an independent concept, MR mixes the best of both Virtual Reality (VR) and Augmented Reality (AR) into the same environment for the user's observation. It covers all possible variations and compositions of real and virtual objects. Building

Information Modelling BIM is able to expand into the management of facilities, maintenance and operations, particularly where integrated with an augmented reality platform such as HoloLens, where BIM-based Mixed Reality application for HVAC system using HoloLens (Bahri et al. 2019). Automated commissioning tools are designed to facilitate the commissioning process, thereby decreasing the time and the skill level required to carry out necessary quality control measures. They enable more thorough testing of building HVAC systems to improve occupant comfort and the persistence of correct system operation. Two tools were developed to perform automated commissioning: (1) the Diagnostic Agent for Building Operation tool, and (2) the heating ventilating and air-conditioning (HVAC) system commissioning tool (Ferretti et al. 2015). The performance was investigated of these automated commissioning tools for the ongoing commissioning of air-handling units using available data and the Technology Virtual Cybernetic Building Testbed as a means to conduct a repeatable evaluation over a range of operating conditions. Shin and Dunston (n.d.) comprehensively identified AR application areas in industrial construction based on suitability of AR technologies through assessing tasks from the viewpoint of human factors regarding visual information requirements to find a rationale for the benefits of AR in work tasks, especially HVAC related installation, like ductwork, scaffolding, installation of steel fabrication, plaster and gypsum board installation. Based on the assessment of work tasks, they presented a comprehensive map that identifies AR application areas in industrial construction. The comprehensive map reveals that there are eight work tasks like layout, excavation, positioning, inspection, coordination, supervision, commenting, and strategizing, which may potentially benefit from AR support. For an AR application to be useful, the accuracy of registration between the real and the virtual world is of utter importance. This is particularly true for operation and maintenance tasks dealing with hidden infrastructure in the built environment. Generating virtual overlay of the infrastructure which accurately aligns with the occluding physical object is the prerequisite for further maintenance procedures, such as locating leaking pipes behind a wall or drawing up a plan for replacing current HVAC utilities of a room (Liu and Seipel 2018). VR can be used in teaching HVAC where the student can move from the classroom to VR before moving to interact with the real equipment. This allows a student to gain experience in a safe environment (Real Skills Conference 2020). Besides, simulation technology also allows companies to train their HVAC techs on heat pumps with heating mode issues that are nearly impossible to replicate in a normal lab. This grants the student the chance to develop familiarity and proficiency and to enhance the user experience. VR allows us to do things that can’t otherwise be accomplished, As much as the virtual world is becoming an integral part of HVAC tech training. By providing the precise alignment of holographic data and combining digital models with the real world, contractors can accurately show how design elements, such as ductwork, will interact with existing conditions, where mixed reality solutions are helping sheet metal contractors and commercial HVAC contractors inefficient ways across the job site (PwC 2020). Augmented Reality-based data visualization system was developed by Lee et al. (2011) to support commissioning HVAC systems during construction, occupancy, and operations phases. Therefore a Building Commissioning data model has been developed to effectively manage such data and facilitate the computational support for commissioning work. One of the challenges of this model-based approach has been to reduce the inefficiency caused by the different and multiple attributes of the Building Commissioning data. To meet this challenge, an Augmented Reality-based data visualization interface was developed that can automatically detect a piece of equipment and visualizes all necessary data relevant to the particular equipment for the commissioning procedures. A video-based on-line AR environment and a pilot cloud framework were used in two aspects: firstly, an environment utilizing web3D is demonstrated, in which on-site images are rendered to box nodes and registered with virtual objects through a three-step method; secondly, it is further extended to be "cloud" through the federation of BIM (building information modeling) and BSNS (business social networking services). During the installation process, the HVAC and water supply drainage engineers logged in cloud BSNS, checked their task schedule, and got published mixed augmentation, which clearly indicated installation positions of different pipes (Jiao et al. 2013). Technical solutions to key issues such as authoring, publishing, and composition are designed. The proposed environment is seamlessly integrated into in-use information systems and therefore enjoys greater usability. Implementations demonstrate how this framework and environment work. VR Technology is advancing faster into the architectural environment in the last few years since it can provide an accurate alignment of holographic information. In the physical environment, this can be combined with the digital models where accurately the contractors can demonstrate how the designed infrastructure, like HVAC, utilities, ducting system, will be interacted with the existing infrastructure, especially for maintenance and development. The effectiveness of technical maintenance assisted with interactive augmented reality instructions was evaluated by Fiorentino et al. (2014). The approach consists of an augmented visualization on a large screen and a combination of multiple fixed and mobile cameras by using commercially available solutions. Maintenance tasks have been distributed among participants based on manual inspections of a machine. Tool selection, removal of bolts, and part disassembly were supported by visual labels, 3D virtual models, and 3D animations. All participants executed similar operations in two modalities: paper manuals and augmented instructions. Statistical analyses proved that augmented instructions significantly reduced participants' overall execution time and error rate. Maintenance tasks performance was compared using instructions on the typical paper manual to the adopted approach that augments the user view with animated ones. The results of the study showed that augmented instructions improve speed and reduce errors, especially in localization, selection of parts.

In conclusion, VR, AR, and MR are playing an essential role in the new era of the HVAC design, installation, and maintenance due to the impressive and helpful advantages in this field. The instruction of this technology can be implemented in the early stages of university level studies to prepare the students for the practical side of their work.

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3

Information Design for Augmented Reality Challenges and Concerns of Interdisciplinary Practice

Joana Casteleiro-Pitrez

1. Introduction

The growing and determinant role of design in contemporary society lies in the attitude of its protagonists. Design intervention areas gain space and meaning through its protagonists. In addition to the messages disseminated through traditional media, design has a fundamental role concerning content creation, and using new technologies. For Stephen Anderson (2019), this is the Design 2.0 moment whose focus is on the design of experiences. The present is not only about designing products/ messages but about projecting experiences and services. The technological paradigm change, the media space reconfiguration, the ubiquity of the devices, and the transmedia content were the drivers of this evolutionary phase. Using the design methodology and the knowledge acquired of various technologies, design today produces experiences for the complex interfaces of the information age in which we live.

John Maeda defined three kinds of design as a working model to build upon: (a) classical design, which pertains to the design of objects we use in the physical world; (b) design thinking, which pertains to how organizations learn how to collaborate and innovate using ideation methods; (c) computational design, which concerns itself with any

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creative activity that involves processors, memory, sensors, actuators, and the internet (Maeda 2016). Maeda defends the idea that the main kind of design out there today is computational design. However, to date, there has been no Bauhaus-like moment for computational designers. Why? Because computation kept evolving at the speed of Moore's Law. Moreover, classical design dogma kept competing with what computational design needed to become (Maeda 2019).

Bearing in mind the two authors' design path described above, we want to understand how these changes reflect in information design. Given this prediction of the present and the future, we ask ourselves whether information design has the interdisciplinary and transdisciplinary nature necessary to relate to the complexity of new media? Furthermore, if the information design historical path already reflects this inter and transdisciplinarity and its adaptation to the new media? After this reflection, we will focus specifically on the Augmented Reality field and its ability to promote new opportunities to explore, analyze and present information. We want to know what studies have been carried out by researchers, what concerns they address, and what terms are applied to report Augmented Reality visualization subjects. Last but not least, we are interested in understanding the extent to which Augmented Reality's challenges and concerns as a mass medium impose on contemporary information design and on the information designer.

2. Information Design, an Interdisciplinary and Transdisciplinary Practice

Now is the time to dream.
(Wurman 2000)

Richard Wurman (2000) starts by referring to the existence of search engines, personalization, and the human being's ability to create, through new software and hardware, personal paths that are transversal to information. The technological capacity allows humanity to dream of things that were impossible only a few years ago. It would be expected that Wurman refers to the importance of visual language and the beginnings of information design, to Egyptian scribes, William Playfair, and the creation of various types of graphics, as well as to Florence Nightingale and the invention and the use of statistical graphs in public reports. However, this does not actually happen; Wurman speaks of the possibility of hyper information. It is precisely the permanent flow of media information, shared at a global level, which has led to a change in the social paradigm. Information society, global village, knowledge society, post-industrial society, network society, among other denominations, refers to today's society. All these concepts reflect this society immersed in information. A society in collision with the third wave of Alvin Toffler (1980), a wave marked by the technological revolution, communication, and the intense exchange of information. A society that Marshall McLuhan (1962) compared as a "global village" and effectively the planet has become a village where it is possible to communicate with everyone who inhabits it. A cyberculture society, where economic globalization, densification of communication and transport networks, creates a single global community, although unequal and conflicted. This community develops together with cyberspace's growth, a communication medium that arises from a computers' connection and the oceanic universe of information that it houses (Lévy 1997). A network society in which the flows of messages and images between networks constitutes the social structure's primary chain (Castells 1999). An era where we can challenge time and space. We stop being readers to become users, stop being just producers or just consumers to become content prosumers, to have more power over information, feel more involved, and eagerly need it.

We go to Google whenever a question arises with the certainty that among the 589,000,000 results, there will be not one but several answers to what we are looking for. We use social networks to observe the social mass surrounding us, known friends, associations and institutions that we like, groups to which we belong, all debiting information (texts, video images) at a furious speed. It is the free newspaper that we leaf through while quickly observing the signs. The mobile phone ringing signaling an e-mail received, the pamphlet at the end of the cinema, the conversations with people, the books we read and then compare with the e-book on our iPad. It is the "age of also" (Wurman 2001). The mixture of diverse types of information comes from multiple media, in different formats, in several languages. We always try to circumvent cultural barriers to get more and more information that we sometimes forget after two seconds. This description is none other than the description of the hyper information era. However, the human brain processes a limited amount of information and acknowledges only a tiny part of awareness of it. So how do we filter out so much information? Choose the one we want? Find our way? As an expert in the cognitive and perceptual processes, the designer assumes a fundamental role in managing informational complexity. Designers transform data into information and information into knowledge that can be perceived and used. Horn corroborates this idea by defining information design as the "art and science of composing information that can be used by human beings efficiently and effectively" (Horn 2000). However, the scope of information design also includes the clarification and optimization of a large amount of complex data, the transmission of non-verbal information, the establishment of connections, the design of the interaction with real or digital objects, and the orientation of the user in three-dimensional spaces whether real or virtual (Horn 2000, Visocky O'Grady and Visocky O'Grady 2008). The designer ponders which resources are best suited to each project, considering the density of information, the audience, and the context. These resources can range from tables, graphs, diagrams, maps, documents for exhibitions, signs, icons, symbols, the development of physical or digital interfaces, 3D simulations, websites, animations, and even the design of Augmented Reality contents.

The need to use all these resources to obtain a more precise and more appropriate communication to the intricate information ecosystem obliges the information designer to acquire considerable knowledge, which underscores his interdisciplinary capacity. Visocky O'Grady and Visocky O'Grady subscribe to this information designer's ability in the following words:

> "Information design mixes typography, illustration, communication studies, ergonomics, psychology, linguistic sociology, and computer science to create concise and direct messages" (Visocky O'Grady and Visocky O'Grady 2008).

For his part, Twemlow elucidates to us about the multimedia capacity of this professional and the need to understand different media:

> "Today, although the designer may be an expert in a particular medium, he must consider that more projects disseminate through multiple channels" (Twemlow 2006).

Lupton goes further and describes transmediality as a characteristic of the new design:

> "The design has become a transmedia enterprise as authors and producers create worlds of characters, locations, situations, and interactions that we can find in a wide variety of products. A game can have different versions, for console, computer, or mobile phone, and even be transferred to merchandising appearing on sweatshirts, lunch boxes, and plastic toys" (Lupton 2006).

This need to work for different media led Pettersson (2002) to demonstrate the interdisciplinary process of what he called message design (Figure 1) through a theoretical model that presented the influence and contribution of the various disciplines in the area of message design.

We reorganized the Pettersson model taking into account the most recent disciplines, technological innovations, and user needs (Figure 2).

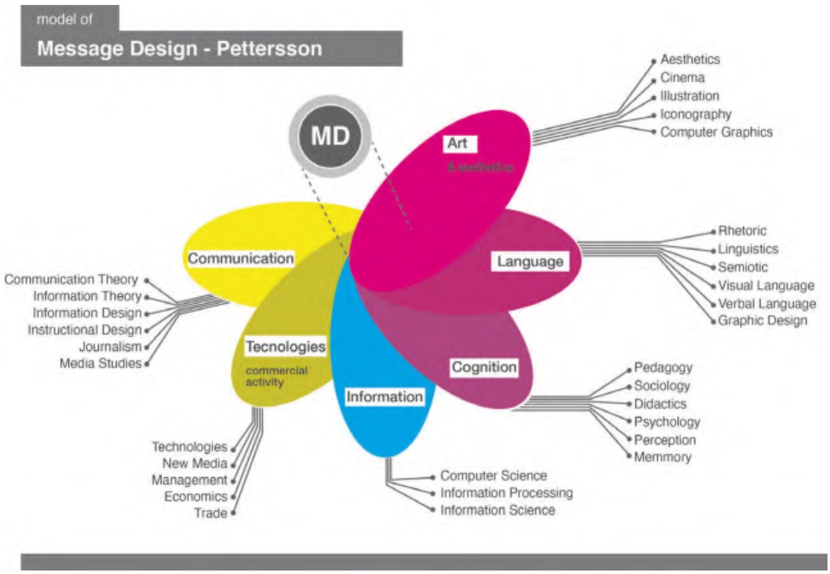

Figure 1. Message design model (Adapted from Pettersson 2002).

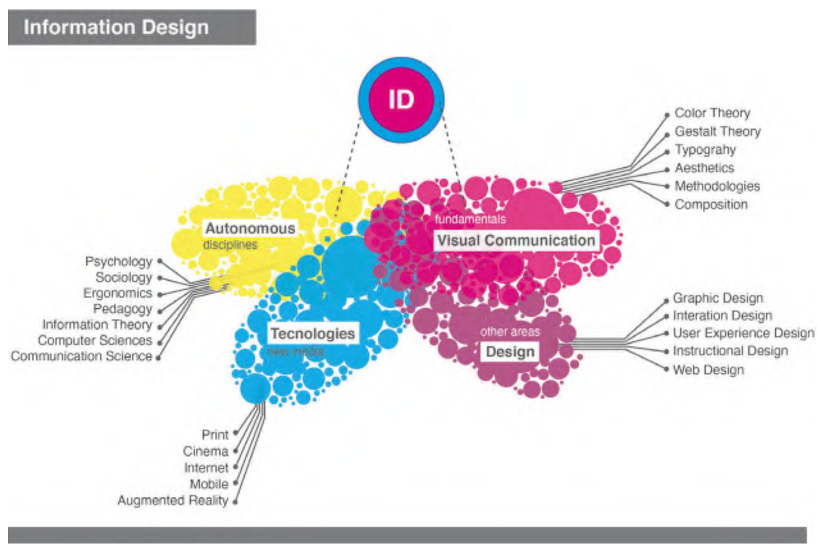

Figure 2. Interdisciplinary information design model.

Information design arises from the overlapping of several fields which we have grouped into four distinct areas:

1) Fundamentals of visual communication (typography, color theory, Gestalt theory, image and shape, grid, composition, aesthetics, methodologies, hierarchy);
2) Design areas. These often overlap, with no defined boundary between them, we can include here:
   - Graphic design;
   - Interaction design, defined by Cooper, Reimann, and Cronin as:

     "The design of interactive digital products, environments, systems, and services. Like many other design disciplines, interaction design is concerned with form. However, first of all, your focus is on something that the traditional fields of design do not explore: the design of behavior [..] The main concern is related to the satisfaction of the needs and desires of the people who will interact with a product or service" (Cooper et al. 2007);
   - Design of experiences that suppose "the creation and synchronization of elements that affect the user's experience, to influence their perception and behavior" (Unger and Chandler 2009), or according to the words of Shedroff:

     "Creating successful experiences in any medium. Considering the design in the three dimensions, over time, the five senses, interactivity, the client, the meaning, and the emotional context. The design of experiences is not just merely the design of web pages or any other interactive medium. The design of experiences can be in any medium, including facilities, printed material, services, events, among others" (Shedroff 2013);
   - Instructional design, "the process by which education is improved through the analysis of student needs and the systematic development of learning materials (IDO 2013)";
   - Interface design;
   - Web design;

   The particularities of each of these areas can be fundamental in the construction of information design projects;
3) Autonomous subjects to design (computer science, linguistics, sociology, psychology of perception, ergonomics, information theory, pedagogy, media study, communication sciences, journalism);
4) New technologies and means of communication (Press, Cinema, Television, Internet, Mobile phones and other gadgets (Mobile), Augmented Reality);

These four distinct areas are guided by research and by the designer's awareness of the context and the audience.

Bonsieppe (1992) speaks to us, in a utopian way, of transdisciplinary design practice. Design assumes itself as a fundamental new discipline of the 21st century, replacing mathematics in the transdisciplinary and foundational role it had in science since the 17th century. Although Bonsieppe's utopian vision is far from being realized, the need for a transdisciplinary practice stems from the development of knowledge, culture, and human complexity. Transdisciplinarity employs aspects of the integration of perspectives and reemerges at the beginning of the 21st century due to the need to share complex problems. Also it verified a lack of knowledge convergence for the resolution of complex issues. The solution may involve the integration of perspectives in the formulation and shared problem-solving (Vieira 2018). These complex problems also stem from the era of hyper information and allow designers with diverse backgrounds and other professionals to converge to find the best solutions. Transdisciplinarity is about transgressing borders between disciplines (Nowotny 2006).

Transdisciplinarity promotes cooperation and contact between different disciplines. Transdisciplinarity is not about total knowledge but an aspiration to lessen particular knowledge. Nicolescu states that:

> "Disciplinarity, pluridisciplinarity, interdisciplinarity, and transdisciplinarity are the four arrows of a single and the same bow: that of Knowledge." (1999)

In other words,

> "as in the case of disciplinarity, transdisciplinary research is not antagonistic but complementary to pluridisciplinary and interdisciplinary research. [...] While recognizing the radically different character of transdisciplinarity concerning [...] interdisciplinarity, it would be dangerous to absolutize this distinction, because in this case, transdisciplinarity deflate of all its content and its effectiveness in action reduced to nothing" (Nicolescu 1999).

The aim of transdisciplinarity is not to overlap but to integrate. Information design has evolved from a unidisciplinary attitude to an interdisciplinary (overlapping disciplines) and transdisciplinary attitude (integrating disciplines). The personalities that influenced the field from several different areas of knowledge (Schuller 2007) fostered these attitudes. Interdisciplinarity and transdisciplinarity remain alive, and Tufte (2009) summarizes it: "it is necessary to use "whatever it takes" (min.42: 58). The designer must use whatever is necessary, expanding his capabilities, and call on other professionals to ensure that the concept is clearly understood, that the task is accomplished, or that the goal is achieved. Papanek's words seem to refer specifically to a transdisciplinary practice stating that "it is at the limits and at the intersection of various technologies and disciplines that discoveries are made" (Papanek 2009).

3. Evolutionary Synthesis of Information Design

Understanding information design in-depth inevitably implies understanding its genesis and its evolutionary process. This understanding also involves raising awareness of the main innovations and their impact on society and in the practice of information design.

Let us start with a fact: the need to comprehend and represent visually is intrinsic to the human being. Therefore, through visual information, ideas, experiences, ways of life were communicated, remembered, symbolized, and preserved. Visual information is a testimony that the spoken word's ephemerality did not allow until a few years ago. Visual language has been used since prehistory as a form of expression and is, therefore, the oldest record in human history (Dondis 2007). The first graphic marks found in Africa are more than two hundred thousand years old. However, most of the marks, cave paintings (Figure 3), and petroglyphs (Figure 4) (simple signs or figures carved or scratched on the rock surfaces) that have been found all over the world are from the period between the higher Paleolithic and the Neolithic (3500 BC–4000 BC). Prehistoric drawings show a high level of observation and memory and aimed towards recording important events, educating the youngest, transmiting information and the magical purposes of interconnecting with the supernatural.

Therefore, these first representations evolved in two directions: first, they were the beginning of figurative art, and second, they formed the basis of writing. The paleolithic artist developed simplification and stylization to the point that some petroglyphs resemble letters (Meggs and Purvis 2009).

This first form of non-verbal communication, created by prehistoric humans, later evolved into Sumerian cuneiform writing. The Sumerians initially intended to record quantities of food and exchanges of goods and did so using pictograms. This visual recording system has undergone several evolutions over the centuries (Figure 5). An example is a case with the change of the scratching material, which is no longer a wooden stylus dragged along a clay tablet, and is now a pointed triangular stylus (in the shape of a wedge) pressed against the clay. This changed radically the characteristics of writing, which becomes more abstract, giving rise to cuneiform writing (Figure 6).

Paradoxically, the Egyptians maintained their pictographic writing for almost three and a half millennia. It was a highly complex script

Figure 3. Lascaux cave painting (15000–10000 A.C.) (Meggs and Purvis 2009).

Figure 4. Galiza Petroglyphs.[1]

[1] Image taken from http://fr.wikipedia.org/wiki/Fichier:Petroglyphe_galice.jpg in 30 March 2021.

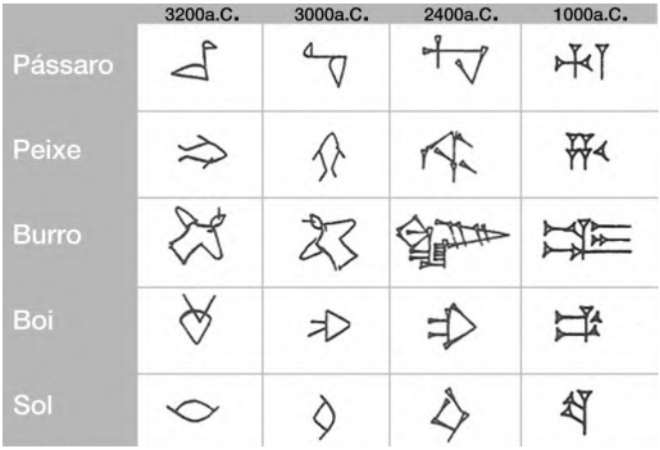

Figure 5. Evolution of Sumerian writing. The pictographic symbols were rotating and becoming more abstract.[2]

Figure 6. Cuneiform writing.[3]

consisting of pictograms, ideograms, and phonetic elements (Mandel 1992). Egyptians use hieroglyphics for historical and commercial documents, poetry, myths, and epics (Meggs and Purvis 2009). Both cuneiform writing and hieroglyphic script have evolved into the writing we use today in a very long process of improvement and adaptation. Visual language never left our daily lives. Through it, we started to

[2] Image adapted and taken from http://ilovetypography.com/2010/08/07/where-does-the-alphabet-come-from/ in 30, March, 2021.

[3] Image obtained http://www.infoescola.com/civilizacoes-antigas/ in 5 April 2011.

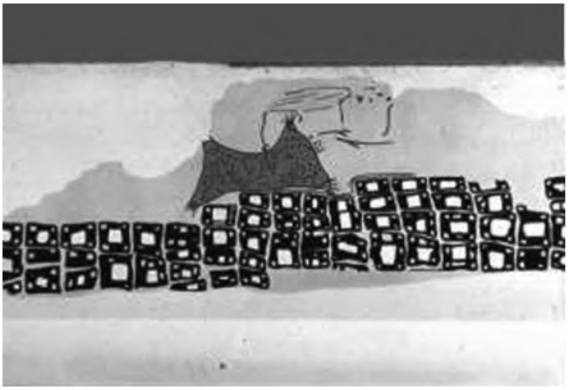

Figure 7. One of the oldest maps known to man, representing the City of Çatalhöyük in Southern Turkey and its Erupting Volcano (6200 A.C.).[4]

Figure 8. Map of the City of Nipur considered the first example of modern cartography, uses orientation, notation and scale (Baghdad – 1300 D.C).[5]

understand the spatial relationships of urban routes. The map of the city of Çatalhöyük in southern Turkey (Figure 7) and the map of Nipur city (Figure 8) underlines precisely the need for human beings to relate to the surrounding space, understanding, and systematizing it.

The use of visual language also helped the perception of complex relationships. When observing the first graphical register of variables

[4] Image obtained from https://digitalhumanities.stanford.edu/çatalhöyük-living-archive-0/ 7 April 2014.

[5] Image obtained from http://www.bookofjoe.com/2008/04/nippur-babyloni.html 30 March 2021.

(Figure 9), we perceived that the transfer of verbal or oral information to a visual platform decreased cognitive effort, quickly amplifying a specific subject's perception, which thus became accessible to a broader range of people. This human need to understand situations beyond his height and gaze which impelled the human being towards the systematization of information, forcing him to make choices about its importance, taking into account his purpose.

We stopped knowing only the urban space to get to know the borders of the world, its seas, and countries through a single visual platform, easy to consult and possible to observe as a whole, and thus what we know today as a map was born (Figure 10). Cartography, therefore, assumes itself as one of the oldest forms of information design.

Throughout history, text and image have enjoyed an intrinsic relationship that we can observe in the illuminated manuscripts of religious nature and works of a scientific nature. Leonardo da Vinci's notebooks are an example of this, full of anatomical drawings and detailed representations of his ideas and inventions. Leonardo is one of the precursors of modern verbal-visual communication and scientific illustration (Pettersson 2002).

The increasing amounts of information and the increase of its complexity promoted new forms of expression to facilitate data visualization. William Playfair presents itself at this time as a leading figure in information design. The engineer and political economist believed that the image was easier to understand than the written word. With the invention of bar graphs (Figure 11) and pie charts (Figure 12), he communicated statistical data that conventionally were presented in tables that are extremely difficult to visualize and understand.

Various graphs, diagrams, and maps started to be included in scientific reports and publications, establishing relationships, describing phenomena, or representing theories and ideas. Some described physical phenomena like those of Michael Faraday (Figure 13) that depicted magnetic forces. Others represented war losses (Figure 14), such as Charles Minard's 1961 statistical graph, considered by Eduard Tufte (2006) as the world's best-designed statistical graph. In it, we can identify six distinct variables and the fundamental principles of analytical design (Tufte 2006):

1) The appropriate and intelligent comparison;
2) The demonstration of causality using mechanisms, structures, and explanations;
3) Use of more than two variables;
4) Integration of pieces of evidence, such as words and numbers;

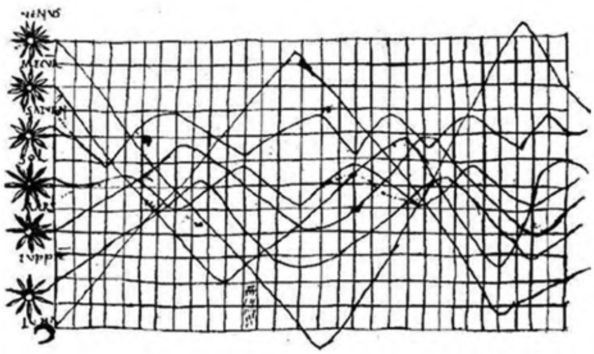

Figure 9. The first graphical record of variables - position of the Sun, Moon, and Planets throughout the year (950 D.C.).[6]

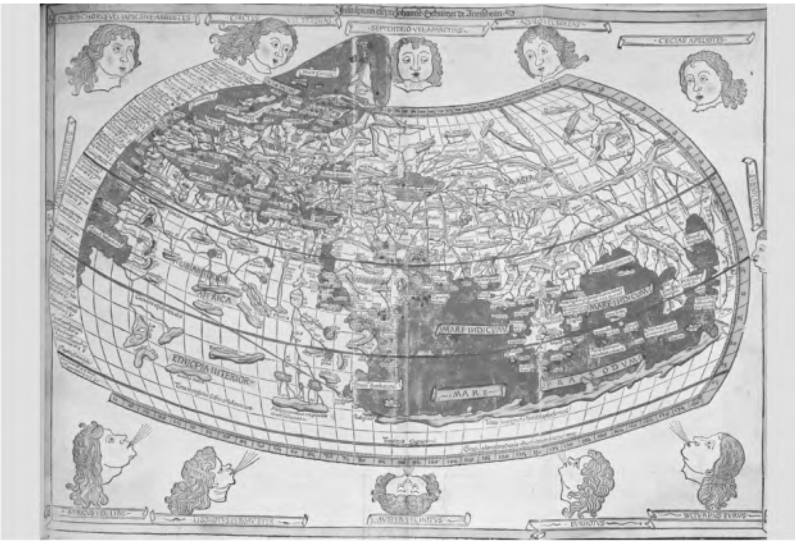

Figure 10. Map based on the descriptions of the book Geographia by Ptolemy (séc. XV D.C.).[7]

5) Integration of documentation through an appropriate title, captions, and inclusion of information sources to corroborate its validity;
6) Choice of content and use of appropriate information.

Other graphs represented data related to public health issues. An example is John Snow's 1854 cholera map, which, although the cause of

[6] Image obtained from http://data-art.net/resources/history_of_vis.php 30 March 2021.
[7] Image obtained from http://www.bl.uk/learning/artimages/maphist/minds/ptolemysmap/ptolemy.html 3 January 2013.

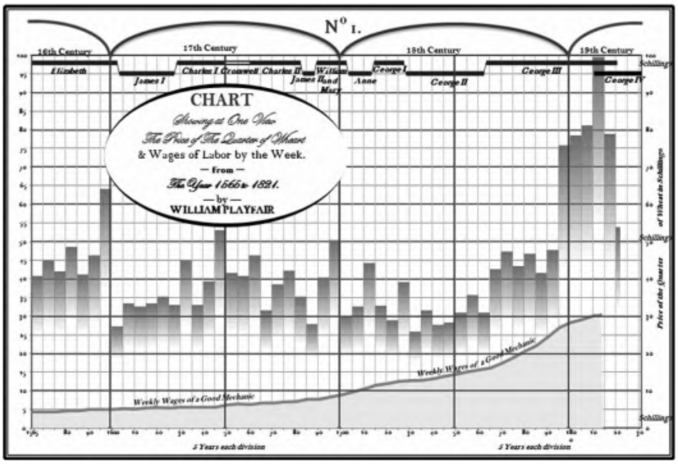

Figure 11. William playfair bar graph that represents the relationship between the price of wheat and labor wages (1786 D.C).[8]

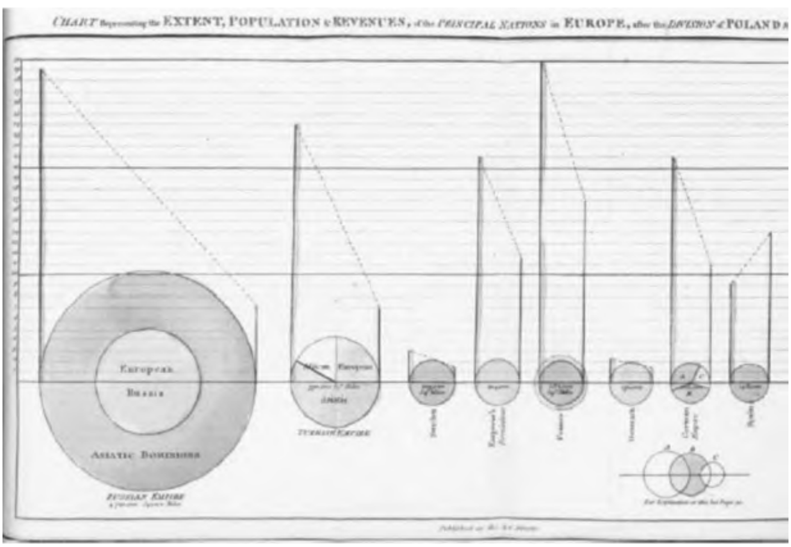

Figure 12. William playfair pie charts (Visocky O'Grady and Visocky O'Grady 2008).

the epidemic is unknown, represented the relationship between cholera cases reported in London and its proximity to water pumps, prompting the establishment of a causal relationship. Years later, Florence Nightingale also used the graphics' persuasive power to represent her theories and recommendations about hygiene in military hospitals.

[8] Image obtained from http://data-art.net/resources/history_of_vis.php in 4 January 2021.

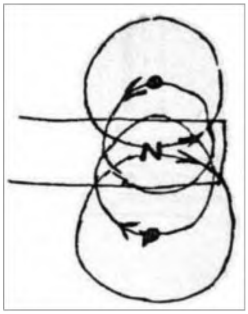

Figure 13. Diagram of a Magnet and its Magnetic Forces (1820 D.C.).[9]

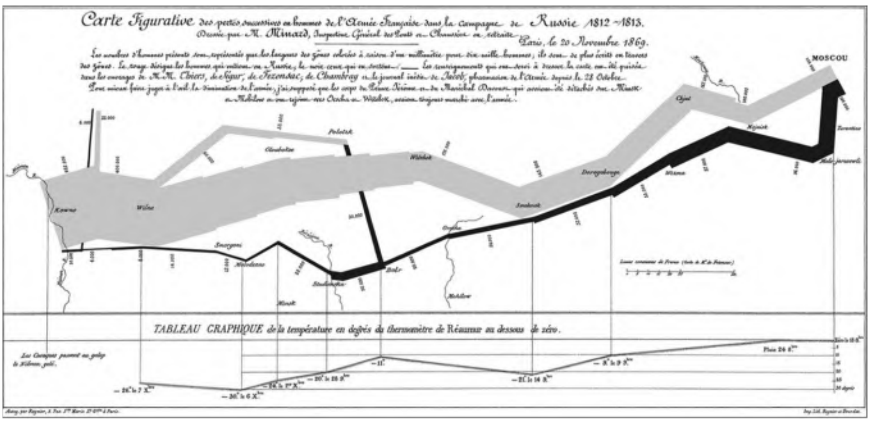

Figure 14. Charles Minard chart depicting the number of men in Napoleon's Army during the Russian Invasion in 1812. The size of the army, the latitude and longitude, the direction, the army's location on specific dates, and the temperature are visible (1968 D.C.) (Tufte 2006).

At the beginning of the 20th century, attention falls on visual resources in pedagogical practice. With the help of Gerd Arntz, Otto Neurath creates the ISOTYPE project (International System of Typographic Picture Education). This project aimed to develop an international visual language (Figure 15) that would allow the presentation of complex socio-economic data through symbols that are easy to understand (one of the techniques consisted of showing numerical values using different amounts of symbols). According to Neurath (1936), the use of the ISOTYPE system's rules would completely change the way of teaching. More than 1,000 different images were created, and the respective rules were developed to maintain a coherent application. The ISOTYPE project's

9 Image obtained from http://www.datavis.ca/milestones/ 9 January 2021.

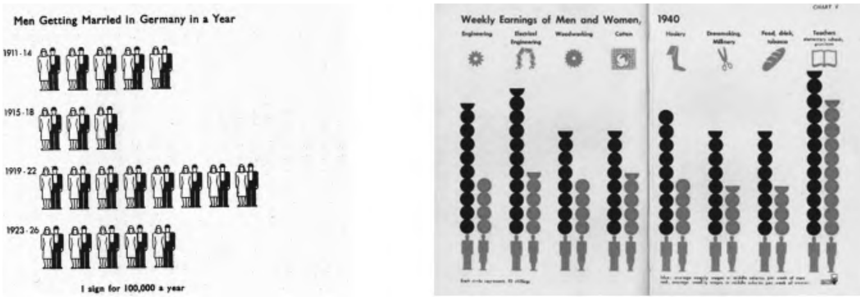

Figure 15. ISOTYPE system graphics (Neurath 1936).

stylistic principles remain the same as in today's international pictograms (Lupton and Miller 1996).

The ISOTYPE System opened the door for the development of visual language accessible and understood by the general public. One of the most relevant practical examples is the design of metro maps. In 1933, Harry Beck redesigned the London underground map (Figures 16 and 17) and realized that passengers did not need to know where the stations' physical location was. They did need to understand the connections and the order of the stations. The simplification of the map and the elimination of geographical connotations made it easier to use and, therefore, more noticeable. This technique is still in use in several transport maps around the world.

Over time, awareness of the target audience's knowledge's importance became an integral part of design practice in information design. The signage projects for the Olympic Games were a challenge in what respected the audience's study by the various teams that integrated it. The problem that arose was that the audience came from all parts of the globe and understood different (verbal) languages. Hence, in 1936, it emerged "in an Olympic context what can be considered the first major attempt to represent sports through symbols" (Rosa 2010).

Later at the Munich Olympic Games in 1972, German designer Otl Aicher presented a pictogram system in which he designed elements according to a mathematical grid. Otl Aicher's work had a significant impact on the universe of creatives and the general public. This new methodology for designing pictograms using a systemic method has become an essential milestone for all designers (Rosa 2010). The use of pictograms, initially inspired by the ISOTYPE project, has been reused, redesigned, and refined (Figure 18).

As we verified the visual information, it was, until now, of static nature, and its observers had a passive role. However, the two American designers Charles and Ray Eames, changed the paradigm. The exhibition they developed for IBM in 1961, Mathematica: A world of Numbers and

Figure 16. London underground map (1932).[10]

Figure 17. London underground map redesign by Harry Beck (1933).[10]

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[10] Images taken from https://londonist.com/2016/05/the-history-of-the-tube-map in 2 April, 2021.

Figure 18. Olympic games pictograms (Rosa 2010).

Beyond (Figure 19), allowed them to create a set of graphic and interactive devices that the user could manipulate. The exhibition contained six interactive units that focused on the concepts: celestial mechanics, Moebius band, probability, topology, minimal surfaces, geometric projection, and multiplication. Each of these six units had a button that triggered different actions when pressed by the visitor. For example, in the probability unit, 30,000 plastic balls fall through a maze of two hundred steel piles, randomly forming the classic bell curve. Today these experimental concepts remain in the most diverse contemporary museums and have expanded to more commercial subjects and locations.

Later, the emergence of the computer and digital language brought new supports for transmitting information and new ways of interacting with it. Muriel Cooper, co-founder of the MIT Media Lab, and Nicholas Negroponte helped frame the modern digital experience. They were investigating the relationship between graphic design and technology and putting into action the visual language workshop (1978) that brought together designers, programmers, and computer scientists who, in a spirit of collaboration and experimentation, outlined many of the digital and interactive environments that surround us today. For Muriel Cooper, it was a new domain of graphic design. In the conversation with Lupton (1994), Muriel Cooper indicates that this new domain has "incredible characteristics that passed through dynamism in real-time, interactivity, malleability, the possibility of learning and adapting to the user or other information, or any other set of relationships." Technology Entertainment and Design (TED) 1995 conference presented one of the most successful interfaces created at the visual language workshop. The interface (Figure 20) consisted of a set of three-dimensional information landscapes where the user's mouse navigated through text organized in three

Figure 19. Interactive exhibition mathematica: a world of numbers and beyond by Charles e Ray Eames (1961).[11]

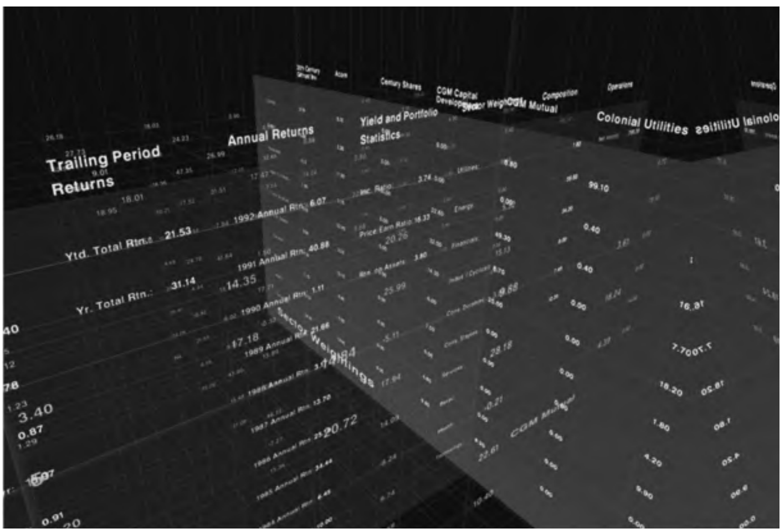

Figure 20. Project developed at the visual language workshop. Financial viewpoints, de Lisa Strausfeld (1995) (Visocky O'Grady and Visocky O'Grady 2008).

dimensions, giving rise to complex, non-linear spaces with multiple hierarchies. Here, the user and not the designer controlled the content's sequence and meaning (Reinfurt 2007).

More than a decade after the first visual language workshop, Tim Berners-Lee's proposal about hypertext connection for fast information sharing led to creating the first browser, editor, server, and first Web page. The World Wide Web came to modify the information world as we knew

[11] Images taken from http://www.exhibitfiles.org/mathematica 16 June, 2020.

it, giving rise to current information society or network society. This digital metamorphosis brought:

a) Access to a colossal amount of information;
b) More and more complex information;
c) Development of software that allows anyone to make graphics and present visual information;
d) New methods and supports to present information (animation, interaction, Virtual Reality, Augmented Reality);
e) Need to create algorithms to perceive and establish relationships between vast amounts of information, the work of Jer Thorp is an example of this (Thorp 2011).

The synthesis described above allows us to distinguish several possibilities for presenting information with different purposes, audiences, and supports. As we have seen, several are those who, coming from the most diverse areas, became interested in the visual presentation of information. Their innovative ideas forever changed the face of information design.

4. From Information Visualization to Immersive Analytics: Where is the Information Design in Augmented Reality Research?

As we observed, information design aims to clarify, simplify, and make information accessible to the people who will need it and use it to make crucial decisions. Information needs to be in a form they can understand and use meaningfully and tell the truth of what things mean and how they work (Katz 2012). Today the challenge is the opposite from that of centuries, or even decades, past: to invent ways of sifting through the multitudes of data that bombard us daily, often numbing our senses and scrambling our brains (Katz 2012).

Augmented Reality provides new opportunities to explore, analyze and present data, and the forms of information visualization include text, symbols, video, graphics, images, animations, static 3D models, and others. The first research presented uses the term information visualization to scope visual contents in Augmented Reality.

Since Augmented Reality advances and tries to establish itself as a medium, some researchers try to understand information visualization challenges.

The study of Furmanski et al. (2002) created design guidelines for information visualization: (a) Distance conveyance: distance and absolute location can be confusing in Augmented Reality, so renderings should disambiguate information about distance or position; (b) Proper motion physics: motion parallax is an essential cue to human observers, so it is crucial that the information in-depth moves in such a way as to convey its proper position; (c) Eliminate unneeded Augmented Reality motion: unneeded motion of rendered material, as well as misregistration, should be eliminated or minimized as much as possible.

In 2011, Kalkofen et al., studied techniques to handle the main obstacles in Augmented Reality visualizations:

1. They discuss approaches to enable a comprehensible integration of virtual objects into real-world environments.
2. Present strategies to manipulate mixed environments enabling to overcome limitations such as narrow fields of view.
3. Present context-driven visualization techniques that automatically adapt Augmented Reality visualizations to their real-world surroundings and the uncertainty of the data involved in generating the rendering.

Later, Bach et al. (2017) described the challenges, parameters, and design space to consider when designing visualizations for an Augmented Reality:

- 2D vs. 3D visualization: Augmented Reality can incorporate both 2D and 3D visualization contents. 2D can lead to perspective distortion and the misinterpretation of visual variables. Pure 3D visualizations, however, may emerge as a means to blend naturally in the environment and may invite interaction and manipulation.
- Visual Clutter: a crowded scene will make it challenging to find space for displaying visualizations without hiding other information. Designers should have the background in mind to blend visualizations seamlessly in color and style; visualizations could be projected onto object surfaces and blend into the object's respective nature.
- Adaptivity: visualizations can adapt to a wide range of conditions: a user's distance to an object, visibility of objects, a user's task at hand, or a current selection, as well as any other measure of relative importance.
- Labels and Legends: The respective background will constrain the readability of text on an Augmented Reality, a label's relative size as well as whether a label is facing the user or not. Labels can be adaptive or designed to be visible only under certain circumstances.
- Relations between physical objects and visualizations: The open problem, at this point, is how to interact with visualizations and artifacts in Augmented Reality effectively.

- Data not related to the physical objects: Eventually, a scene or an activity may need access to data and information not related to any physical object. Empty spaces in the scene could serve to show that information.

Today, the robustness, availability, and affordability of Augmented Reality systems push information visualization farther away. The new possibilities the medium promotes and the large amount of data the user has to deal with induces the creation of the term Immersive Analytics (IA). This expression was first introduced by an information visualization research cluster at Monash University in Australia and adopted by IEEE (Irshad et al. 2018). IA's field mainly focuses on the design and development of display and interaction technologies for immersive environments to enhance the way users visualize, comprehend, and analyze data. In a more specific way:

> "Immersive Analytics investigates how new interaction and display technologies can be used to support analytical reasoning and decision making. The aim is to provide multi-sensory interfaces for analytics approaches that support collaboration and allow users to immerse themselves in their data. Immersive Analytics builds on technologies such as large touch surfaces, immersive virtual and Augmented Reality environments, haptic and audio displays, and modern fabrication techniques (Chandler et al. 2015)."

Today, Augmented Reality is being considered as a support for information visualization (Irshad et al. 2018, Luboschik et al. 2016) and applied to Industry (Mourtzis et al. 2018) spatial data for medical imaging (Chan 2020) bioscience (Müller 2018) heritage (Marques et al. 2017), education (Dehghani et al. 2020) among others. Augmented Reality technologies were adopted by scientists to enhance the users' perception and help them see, hear, and feel information in their environments and in new and enriched ways.

Conscious of these new possibilities in Augmented Reality, recent studies tried to understand the visual perception for IA in Augmented Reality (Whitlock et al. 2020) and discover that:

- Estimating size with four data dimensions is significantly more challenging on desktop displays than in Augmented Reality.
- Depth became more effective and size easier to distinguish from depth in Augmented Reality and Virtual Reality than in desktop. While traditional visualization guidelines strongly advocate against 3D visualizations using depth, stereoscopic viewing may alleviate many concerns with these designs.

- Color was significantly harder to use in Augmented Reality. For participants, color in Augmented Reality was challenging due to interference from the background color of the room. Future work should consider how to select visualization colors for IA intelligently. One strategy is to draw on techniques for colorblind accessibility to ensure a more robust color design.
- Participants use their bodies or objects around them as referents to help with size, height, and depth estimation in Augmented Reality.
- People moved significantly more in Augmented Reality than Virtual Reality. We anticipate these differences reflect increased situational awareness and embodiment offered by Augmented Reality: people can see the space they are moving in. This comfort may suggest different uses of physical space for configuring visualization systems in Augmented Reality. Putting it simply, people may make better use of space outside of their field of view in Augmented Reality to create constellations of visualizations that they can navigate more fluidly and comfortably.

Like in the work of Zollmann et al. (2020), we analyzed different studies in visualization for Augmented Reality. We agree with the authors that it is possible to group these works into categories, it becomes clear that researchers consider contextual information one of the points to consider (Geuss 2020, Grubert et al. 2016, White et al. 2019). We also found that visual coherence seems to be a commonly addressed aim in Augmented Reality visualization techniques research (Alhakamy and Tuceryan 2020, Collins et al. 2017). Particularly light/illumination techniques (Kán and Kafumann 2019, Wang et al. 2019) and the shadow techniques, such as Diaz et al. (2017) proved that cast shadows are an important design decision for improving spatial perception. Also, depth (Whitlock et al. 2020) and occlusion (Itoh et al. 2017) cues are vital components to achieve visual coherence in Augmented Reality applications. Reducing information clutter is similarly popular for Augmented Reality visualization techniques (Bach et al. 2017) and specific Augmented Reality content, like text and legibility (Leykin and Tuceryan 2004).

How we can observe visual information and visualization are areas of interest by Augmented Reality researcher's community. Even though the maturity of Augmented Reality is proclaimed by Gartner (Herdina 2020, Walker 2018), researchers seem to focus on particular topics and techniques to improve perception and the virtual/real overlap. Somehow researchers did not choose the term information design to appear in these studies. On the one hand, we think that appended because researchers found other terms like immersive analytics to be more popular and a novelty. On the other hand, it could be because they focus on particular techniques and use the umbrella term visualization. Finally, the constant technological advances and the search for a consolidated visual field in Augmented Reality are in the beginning and need more design studies that focus on visual perception, aesthetic, cognitive, and visual connotations of contents and interfaces. So, what is the role of information design and information designer in Augmented Reality projects?

5. Information Design and Augmented Reality: Challenges, Concerns, a More Complete Designer?

Augmented Reality technology reached a "good enough" level; it is now up to designers to bring technology to the masses in a significant way.
(Inbar 2013)

Augmented Reality is considered the eighth mass medium (Craig 2013). However, we know that this formalization will depend on its implication within the mass culture itself. For information design, this possibility that Augmented Reality entails—ceasing to be a technology to become a medium—makes it extremely attractive. On the one hand, because the designer's intervention will be fundamental for metamorphosis to happen, only through design will we be able to make technology more meaningful and closer to the human beings, meeting the various voices that arise in this direction (Inbar 2013, Papagiannis 2011, Papagiannis 2013, Papagiannis 2017). On the other hand, Augmented Reality transformation in a medium implies the need to create and reflect new aesthetic, graphic, and interaction paradigms that will influence new generations. And finally, because Augmented Reality asserts itself as singular support for the work of the designer.

As a medium, Augmented Reality is understood as a "mediator of ideas between humans and computers, humans and humans, and computers and humans" (Craig 2013). And affirming itself as a medium and not just as mere technology, Augmented Reality can be used to provoke emotions, tell stories, document moments and events and create unforgettable experiences. The designer's intervention will be indispensable to fulfill these objectives.

Augmented Reality, then, presents itself to our eyes as a blank sheet waiting for intervention not only of a technological order but mainly a creative, conceptual, aesthetic, and functional intervention. There is the possibility of forming new conventions and developing a new language specific to this medium. We would say that it is a unique moment that allows each designer to become a pioneer similar to what happened with the Internet, where names like Jacob Nielsen and Donald Norman founded the foundations of usability. Or the case of Hillman Curtis, whose futuristic spirit made it possible to transform the Internet into a multimedia platform where sounds, videos, text, images, and animations coexist. Curtis confessed that "the reason for designing for new media is simple—To subtly and quickly change the world" (Vitello 2012).

Another example is Luke Turner, who created in 1998 one of the first websites where the menus were not restricted to a specific area of the screen but integrated with the whole. The website's three-dimensional objects stood out from the background and are noticeable among the other websites created with text and columns based on HTML tables. We also highlight other names such as Eric Jordan and Martin Hughes. Eric Jordan made in 2001 what was considered the most influential Adobe Flash site of the decade. Martin Hughes transferred analog elements to the screen that could be animated (from a CD case to a cigarette pack). These, among many others, helped to build the aesthetic bases of the Web. In cinema, the same phenomenon is notorious. New aesthetic models and new styles have emerged from the exploration of various creative minds. Like the case of Georges Méliès and the representation of illusion (starting what we know today as special effects). Stanley Kubrick and the perspective of a single point, Quentin Tarantino and the preference for the aesthetics of violence, and Wes Anderson and the use of symmetry. We thus confirm that aesthetics has always been linked to the study of the media.

Walter Benjamin (1992), in his essay "The work of art in the age of its technical reproducibility," argues that photography and cinema were changing the way the culture was perceived worldwide. Mcluhan (1964) follows the same line of thought and extrapolates this idea when he writes "The media as extensions of man". Here he defends the thesis that the press's technology-led the human being to categorize the world in a certain way, in the same way, that television would be instigating fundamental perceptual changes. Technology has changed the way we perceive and even think. We believe, however, that this is due in large part to the new aesthetic languages that each new medium has allowed to address. We identify here a kind of cycle where the emergence of new technology leads to the creation of its aesthetic language, and the creation of the aesthetic language, and in turn, leads to the use of that same technology by the human being, which induces perceptual and conceptual changes. Summoning the words of Victor Papanek:

> "The ultimate design work is to transform the environment and the human beings' tools and, by extension, to change the man himself" (Papanek 2009).

Augmented Reality, its profusion, and aesthetic language, has even influenced traditional media, as is the case with LEGO and National Geographic Channel HD posters, where printed images overlap the real world (Figure 21). The Augmented Reality and television combination is also visible in the InAiR proposal, which uses several layers of information from the Web.

Figure 21. LEGO and National Geographic Channel HD posters.[12]

Thus, we observe that each new medium's effect is always the sum of the impact of the media that preceded it (Mcluhan 1964). However, each new medium has unique characteristics that differentiate it from the others, which is why we cannot treat these systems like the previous ones. Nilsson and Johansson (2006) even confirm the incongruity of conceiving Augmented Reality projects along the same lines as traditional graphic interfaces. We assume that the current phase of development incites a search for the identification and construction of its aesthetic characteristics and the establishment of new forms of use. As with other previous media, the first projects that connected the design field with Augmented Reality started from the principle that it was a common graphical interface. However, considering its stage of development, we can already point out some of its characteristics within the vocabulary of information design.

a) Personalization of the contents concerning the user;
b) Contextualization of the contents concerning the environment;
c) Unlike the modernist design of the twentieth century that proclaims the visually unified integration between the elements. With Augmented Reality, the visual field does not always have a coherent graphic language, since images from the real and the virtual integrates into the same space (Bolter et al. 2013);
d) Some shared content comes from a unique perspective of the user (it is their point of view that we see in a photo or video);
e) The user's point of view interferes with the visualization;
f) Augmented Reality is a medium primarily based on vision. However, the human being has a way of interacting with different media, watching television, reading a book, listening to the radio. In the case of Augmented Reality, the human being experiences it (Craig 2013);

[12] Images taken from http://www.3lemon.es/los-3-limones-de-la-semana-4/ and http://www.dragteam.info/ 12 de October, 2013.

g) If Web 2.0 already presupposed the creation of an audiovisual environment with the illusion of approaching reality, Augmented Reality takes a step forward and makes Reality an integral part of the interface;

h) The interfaces are transparent and more intuitive.

All of these characteristics must be seen as a possibility and not as an obstacle. The Icograda design education manifest references Augmented Reality as one of the technologies that will expand the way designers communicate since it is assumed as a communication support. Following the suggestions of the Manifesto (Bennett and Vulpinari 2011), "the designer must adapt to technological change with ease, mastering new ways of visualizing and communicating concepts through different media and new materials." Thus, we believe that the designer must take into account the following issues when working in the context of Augmented Reality:

a) Augmented Reality projects imply interdisciplinary knowledge;

b) The designer must define the type of technologies and devices to be used;

c) Sometimes, there is a need to establish time limits for the use of the systems, taking into account the display device used, preventing user fatigue;

d) The designer can reinvent the text-image relationship and the sound-movement relationship;

e) The designer must take into account the possibility of controlling, or not, the environment. For example, an application at night will have implications for the user's visual perception. A night image is darker than a daytime image which implies that the designer must prepare the virtual elements for these changes;

f) The possibilities of synchronization with other devices and other software must be taken into account. Today the motto is less information, more integration. It is no longer enough to design the perfect software. The market wants to know how it will integrate with the other programs. This forces creators to carry out further compatibility tests and obliges them to follow specific standards. Internet connects all aspects of our lives. Thus, we need total communication, not only between humans but also between our devices, from toasters to PDA's. We want everything to be connected so that the information is synthesized and constantly updated (Wurman 2001).

g) Due to the novelty of these systems, the designer must include instructions for use in the interface, app, or product;

h) The designer must consider an approach that we have called hyper-responsive. This new concept is based on the responsive web design approach coined by Ethan Marcotte in 2010. It refers to a website's ability to adapt to different devices, providing an excellent browsing experience, and served us here as a basis for new considerations. Since in the case of Augmented Reality it is not just a question of adapting to different visualization devices, the interface and layout must be adaptable to physical, temporal elements, proximity factors, distance, orientation, position, and even the user mood.

These new considerations demonstrate that we are, before a more complete information designer, whose concerns are not limited to visualization but visualization through a new medium whose characteristics can never be neglected. Today's information designer has to understand new concepts, manipulate new elements and new knowledge and still perceive a new set of relationships constantly changing as technology advances.

In the near future, we believe that haptic interfaces, gestural interfaces, the point of view brought by Augmented Reality glasses and lenses, and other wearable devices will allow even more possibilities. Both the design and Augmented Reality areas will benefit from the union of the two pieces of knowledge. New challenges arise, and Bonsieppe's words make us reflect on the ability of each designer to embrace them:

> "With the new media, designers face many challenges, demanding certain intellectual faculties, such as mastery of the written language and basic programming concepts. I do not know, however, if designers well look this. Thus, design can be an endangered profession because it can be that other professionals are better able to take on these challenges" (Bonsieppe in Macarena 2005).

Unlike Bonsieppe, we believe that new generations of information designers are preparing for these challenges. These new designer generations do more research, experiment with new media, assume an attitude of integrating other disciplines, and pursue the computational design that John Maeda (2019) identified as the most important of this generation.

6. Conclusion

Augmented Reality assumes itself as a medium where visual information is critical, especially when the need to present more and increasingly complex information opens up new possibilities. This work reflects on information design and its relationship with Augmented Reality to approximate concepts and encourage this term's use in future studies.

We can conclude that information design adapted to the changes that arose from the information society. Design was forced to acquire considerable knowledge and admit other disciplines in his field of action to communicate clearly and appropriately through diverse media. Design evolves from a monodisciplinary attitude to an interdisciplinary and transdisciplinary perspective. Interdisciplinary attitude insofar as it is capable of overlapping disciplines to achieve an objective and transdisciplinary attitude insofar as it integrates disciplines to arrive at a solution. This inter and transdisciplinary are fundamental when proposing solutions for Augmented Reality projects. We also observed that the historical path of information design has consistently used external disciplines, people with different backgrounds, to adapt to society's challenges and the new media.

Information design aims to present information clearly and perceptibly, and Augmented Reality has offered new opportunities for information visualization as a mass media. The first studies reflect on Augmented Reality visualization, the most recent ones, taking into account the technological evolution, reflect on the possibility of presenting and analyzing complex information called immersive analytics. The areas that have most attracted researcher's attention and concern in Augmented Reality information visualization are contextual information, visual coherence, and information clutter.

In most studies, the term information design has been neglected at the expense of the term information visualization, visualization, and immersive analytics. On the one hand, because these terms are more recent, on the other because the studies focus on very particular techniques such as the case of shadows, light, depth, and occlusion. Finally, Augmented Reality is not yet a stabilized medium. This stabilization will allow moving forward in visual perception study, aesthetic and cognitive exploration, forming a basis for this medium's information design.

Augmented Reality poses challenges, considerations, and concerns to design and information designers that are not limited to visualization but visualization through a new medium whose characteristics designer cannot neglect. Augmented Reality presents itself to us as a blank sheet waiting for intervention not only of a technological nature but mainly intervention of creative, conceptual, aesthetic, informative, and functional nature, areas that belong to the domain of information design.

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4

A New Role for Design in the 21st Century From Operational to Tactical and Strategic

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José Mauro Nunes[2,5]

1. Introduction

Design emerges in the 21st Century as a renewed discipline, prompting the World Design Organization (WDO) to redefine it in 2015 as

> "a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences" (WDO 2015).

The WDO definition's approach at the same time liberates design from a partial and inaccurate association with the arts, which frames it only from the viewpoint of the creation of meaning through form. This outdated (art related) vision nonetheless still endures and frequently prevents design from being properly understood and applied to a number of complex situations. Above aesthetics, design is a problem-solving process which has applications far beyond its origins as an applied art.

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In this article, we intend to trace the identity of this 21st century renewed design, through our three concurrent and complimentary views, which highlight design's new territories, its ability to create new models, and finally to stand up to the current and future challenging dystopian scenarios.

2. Four New Paradigms of Design in the 21st Century: Dematerialisation, Transdisciplinarity, User Protagonist and Soft Methodologies

In the last decades of the 20th century, we observed the emergence of new design practices that might change the scorched image traced by such harsh examples of criticism. This is the subject of our investigation, advocating that a considerable change might be occurring in design, resulting in a renewed and stronger discipline, which is more capable of giving support in order to face the challenges we have ahead of our society.

Starting to map this shift, we examine evidence pointing to four attributes of design in the 21st century: Dematerialisation, Transdisciplinarity, User Protagonist and Soft Methodologies. These are new charts for new design territories.

2.1 Dematerialisation

The genesis and the very essence of Modern Design is in the form, the aesthetic of the object, as an answer to an urge of the mass production of industrialized consumer objects. It was an awakening call for consumerism inspired by a materialistic post-Nietzschean world where god is dead, where the bourgeoisie post French revolution aspires to immodestly exhibit wealth while *"celebrating the material progress and the rise of international trade after the end of the Napoleonic Wars"* (Patrocinio 2013).

The materiality of objects came to be the fulcrum of the Bauhaus industrial design, stressing the truth of materials and industrial processes, setting the spirit of modern design. This was expressed in the discourse of Walter Gropius at the opening of the 1923 Bauhaus exhibition, where *"he proclaimed his belief in a new unity between art and technology"* (Margolin 2017). But Gropius himself, nonetheless to his commitment to the formalist principle of the *truth of materials*—so dear to Bauhausians and constructivists—declared that *"the aesthetic satisfaction of the human soul, is just as important as the material"*—and that *"whereas building is merely a matter of methods and materials, architecture implies the mastery of space"* (Gropius 1965).

This displacement of value from material to immaterial was not a previously unvisited concept, being frequently retold by moral or philosophical texts. Lao Tzu, the Chinese wiseman from the 6th century BC, offered his reflexion on the value of intangible things in his Tao Te Ching (a text much cited, and amongst others by Victor Papanek):

> Thirty spokes will converge
> In the hub of a wheel;
> But the use of the cart
> Will depend on the part
> Of the hub that is void.
>
> With a wall all around
> A clay bowl is molded;
> But the use of the bowl
> Will depend on the part
> Of the bowl that is void.
>
> Cut out windows and doors
> In the house as you build;
> But the use of the house
> Will depend on the space
> In the walls that is void.
>
> So advantage is had
> From whatever is there;
> But usefulness rises
> From whatever is not.
>
> (Blakney 1983)

Talking about the essence of things, Lao Tzu advises us that it does not abide in the objects, but in the use we made of them—cart, bowl, or house. This seems to be in consonance with the current shift from products and materials to the experiences provided by them.

The leasing or renting of cars, sharing of rooms or apartments on AirBnB, renting power tools and even furniture, the streaming of movies and music—all dematerialized. Even the relation of medicine with our bodies is now largely mediated by digital imagery and data from lab tests, and is also dematerialized.

Service design, product-service systems, user experience design (UX), virtual and augmented realities, internet of things, app-oriented online life. Design is confronting dematerialization. Even the term *product design* has dematerialised itself, from the design of material objects as it was understood in the 20th century to the design of solutions or systems—as intangible as it might be. Stretching this idea just a little further, Yuval Harari foresees *virtual-world designers* as a near future profession, in a world where virtual and real increasingly exchange roles (Harari 2015).

Thomas Mitchell discusses the arrival of a Human Age towards the end of the 20th Century, following the previous ages of hardware and software. Since the technology is available to anyone, *"the user's experience, rather than the physicality of the product, becomes the focus; the traditional concept is extended from physical objects to intangible processes"* (Mitchell 1988).

From these examples, we imply that design is dematerializing, moving the importance from things to experiences. But design dematerialization also means that design needs to be less intensive in resource consumption. Dematerialization also means degrowth, the use of less materials, of renewable or sustainable materials, the design of durable and recyclable products, and the design of fewer products. Dematerialization means designers have to be accountable for their role in generating waste and spending natural resources, especially non-renewable ones.

2.2 Transdisciplinarity

A term attributed to Jean Piaget (1972), *transdisciplinarity* has been around since the early 1970s. At that time, the revolutionary idea of a system of relationships between different disciplines that would not have any defined boundaries fuelled discussions of the future of knowledge and research. According to Lawrence, transdisciplinarity *"challenges knowledge fragmentation"* (Lawrence 2010). A resurgence of transdisciplinarity in the 1990s is described as related to the urge to solve highly complex concerns (Bernstein 2015). Such problems were also the focus of the work where Lawrence published his essay cited above: Tackling Wicked Problems through the Transdisciplinary imagination.

The context where Piaget brought up the issue of transdisciplinarity was the discussion of a framework for knowledge exchange in the classroom through cooperation amongst different disciplines. Such an exchange can be labelled as either MULTI, INTER (or CROSS), or TRANSDISCIPLINARY, while a discipline in isolation receives the prefix UNI (or MONO).

To better understand this process is proposed the UMIT Model (Figure 1), evolving counter clockwise the degree of interaction from isolated disciplines to a transdisciplinary blend.

- **UNIDISCIPLINARITY** means a *COMPARTMENTALIZATION* of knowledge, where disciplines are *ISOLATED IN SPACE*.
- **MULTIDISCIPLINARITY** means *SHARING* the knowledge, while disciplines *INTERACT IN SPACE*.

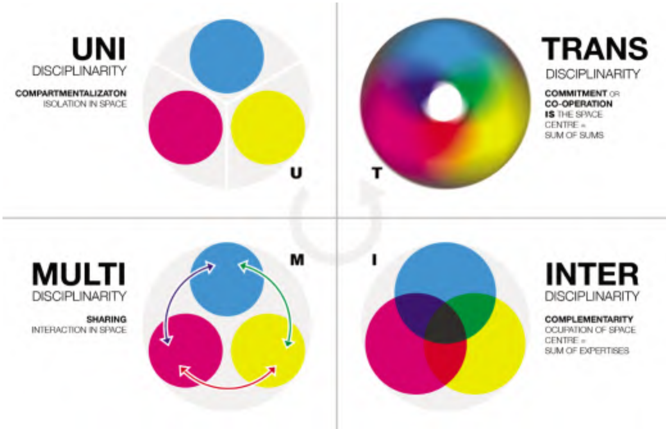

Figure 1. The UMIT model of unidisciplinary, multidisciplinary, interdisciplinary and transdisciplinary exchange of knowledge (source: G. Patrocinio, course material, September 2016).

- **INTERDISCIPLINARITY** implies *COMPLEMENTARITY* of knowledge, defining an *OCCUPATION OF SPACE*, being the *CENTRE* of the *SUM* of *EXPERTISES*.
- **TRANSDISCIPLINARITY** implies *COMMITMENT* or *CO-OPERATION* between different knowledge areas; it *IS THE SPACE*, and the *CENTRE* is the *SUM OF SUMS* of the different areas involved.

The incidental difference between the superposition of colours in the interdisciplinary space, that is mixing each one in pairs and then all together forming a darker, and consistent result, and the central white (or void) formed by the gradient of colours in the transdisciplinary space brings an additional perception of the distinction between them. At a given point, each discipline keeps its vertical depth of knowledge, represented by its own pure colour, but they are blended in a rainbow of colours when brought together, which then reaches the centre as white.

In the transdisciplinary model, the variation of shades toward the outer and inner surfaces also suggests a similarity to a three-dimensional mathematical figure, the torus. This figure allows us to establish an unusual, but convenient, connection with the field of psychoanalysis. Freud suggested the use of topographic schemas to navigate the human psyche. Lacan followed him in the use of complex mathematical forms as topological devices, among which we will find the torus figure, which is where the void in the centre responds to the object of desire. This apparently blank space is sometimes identified in psychoanalysis as the structuring void. Here we say 'apparently' because it is not exactly blank, but in fact the sum of the sums of different skills and knowledge, which in terms of the colour metaphor used translates as white. However, this white hollow centre of the torus in the transdisciplinarity representation in the UMIT Model is not to be considered as the opposite to the dark and consistent centre of the interdisciplinarity. It rather suggests the differences between those approaches, which is if one may be darker and denser the other is lighter and open to creativity and the generation of new knowledge.

This lightness and openness towards the new unravels why transdisciplinarity is a paramount component for a New Design model. The age of the designer-author gives space for the designer-team-member, or even a team leader, considering the skills developed from being an intrinsically transdisciplinary activity. But we should consider that fundamentally, transdisciplinarity is rather like an attitude, you cannot assemble a transdisciplinary team beforehand. Transdisciplinarity is eminently a behaviour, or else a team practice. Professor Margaret Somerville explains that a transdisciplinary team works differently according to their mix, just like a cake recipe bears different outcomes depending on the way ingredients are added, mixed, and cooked (UNESCO 1998). So, a diverse but appropriate mix of skilled people and a well-informed and prepared leadership is the foundation for a transdisciplinary team approach.

As a corollary to this convergence of Design and Transdisciplinarity, Design skills have been ultimately associated with the ability of leadership in transdisciplinary environments, prompting it to be appointed as a desirable newcomer to the C-Suite of Twenty-first Century companies. This is not unpredictable considering the extraordinary performance of design-driven companies. Every executive is paying closer attention to the effects of design-led innovation. Examining articles in business magazines and consultancy companies such as Forbes, Fortune, Harvard Business Review, Telegraph, and McKinsey, all of them have in common the importance attributed to a new role of Design amidst the so-called C-level executives. The Chief Design Officer is already a trend from big companies such as Apple and PepsiCo to banks, insurance companies, fintechs, internet unicorns, and startups. This is true of cities too, Helsinki appointed Anne Stenros its first CDO in 2016, a trend which was followed by Los Angeles, USA, and Edmonton, Canada, amongst other cities around the world. The use of design to leverage development is not a new policy tool, as it was already recommended in the early 1970s by the United Nations Industrial Development Organization, UNIDO (as reported in Patrocinio and Nunes 2019). But it was only in the 21st century that was seen an extraordinary boost in the policies of design and in the use of design as a tool to innovate policy-making, especially in the second decade.

To achieve completely this much-sought ability to act transdisciplinary, design should satisfy the attribute described long ago by László Moholy-Nagy: *"The idea of design and the profession of the designer has to be transformed from the notion of a specialist function into a generally valid attitude of resourcefulness and inventiveness which allows projects to be seen not in isolation but in relationship with the need of the individual and the community"* (Moholy-Nagy 1947). Or else, as he points out in the same text: *"designing is not a profession, but an attitude"*—and we could argue that this attitude should be empathetic and transdisciplinary.

2.3 User Protagonism

Ellen Lupton preconizes a "birth of the user" as a consequence to the "death of the author" announced by Roland Barthes while arguing *"the importance of the reader over the writer in creating meaning"* (Lupton 2010). But can we follow this rationale of Lupton/Barthes, in extrapolating the death of the author as the death of the designer, and as a corollary jump to the conclusion that everyone is then a designer? Victor Papanek's most misunderstood sentence sets the opening of his seminal book of 1971, Design for the Real World, where he dropped the bomb *"All men are designers"* (Papanek 2009). After that, a few authors have once in a while declared that "everyone is a designer"—from Tim Brown to Donald Norman. Searching Google for this phrase will return about 1.490.000 results (in February 2021).

The semantic mystification around the word design was exposed by John Heskett with the example *"Design is to design a design to produce a design"* (Heskett 2002). Here the word design appears as a verb and also as three nouns, each one bearing a different meaning. As he points out, it is essentially a difference between a verb (to design) and a noun (design), this is later understood as a field of professional activity. The ability to design is inherent to any human being (and is also observed in many other so-called "irrational beings"), but it doesn't mean to be a designer, in the sense that we understand a defined activity exercised by trained professionals. Contributing to this discussion, Ezio Manzini proposes a distinction between the ***expert design*** and the ***diffuse design***:

> "Here lies the definition of a field of possibility for those who design, between the two poles of diffuse design and expert design, where diffuse design is put into play by 'nonexperts,' with their natural designing capacity, while design experts are people trained to operate professionally as designers, and who put themselves forward as design professionals" (Manzini 2015).

But what is the role of the nonexperts? According to Bratteteig and Wagner, "Users contribute with expert knowledge of the context" (2014).

They go on explaining the concept for a participatory design approach, which "differs from other user or human-centred design approaches by its emphasis on users as co-designers during all stages of the design process, not only as information sources for designers' ideas or testers of more or less finished design results" (Bratteteig and Wagner 2014).

Evidence of how the user became the protagonist also comes from the recent field of *emotional design*, a term formulated by the cognitive scientist Donald Norman in the early 2000s. Norman proposed it as a way to describe *"the affective reactions that people have to products and their interactions with them"* and how designers use *"emotional affordances"* to achieve this level of involvement of and with the user (Norman and Ortony 2003). He then developed *"a framework for analysing"*, but also for developing, *"products in a holistic way to include their attractiveness, their behaviour, and the image they present to the user—and the owner"* (Norman 2018).

Going back to Lupton's reasoning cited above, Barthe's death of the author can be associated with the decline of the designer-author and the corresponding rise of co-designing, transdisciplinary teams, and the ascent of the user to a protagonist role, beyond and above the *centre* of design (as in user-centred or human-centred design).

When, in January 2021, the European Commission unveiled the plans for a New European Bauhaus, it was announced as "a broad dialogue between designers, artists, scientists, architects and citizens who can provide ideas and help to identify the most urgent needs and challenges" (Nicolás 2021). The proposal, launched by the commission president Ursula von der Leyen in 2020, started with a call to action, under the participatory premises that involved players from different areas co-designing the programme. Novelty starts with the expression co-design, used to qualify the process that brings together designers, specialists, and citizens, recognizing procedures adopted by the state-of-the-art design methodologies of the 21st century that places the end-user in the centre of the process. Transdisciplinary and participatory, the adoption of such methodologies validates the premise of new design territories being explored, with the user as protagonist.

2.4 Soft Methodologies

The philosopher Zygmunt Bauman has discussed how humanity passed from *solid* to a *liquid* modernity, where social structures *"decompose and melt faster than the time it takes to cast them"* (Bauman 2007). His prospect of our decomposing society is not bland or pleasant. But his understanding of its fluidity frequently cites Marshall Berman's book about post-modernity as vanishing in the air (*All that is solid melts into air: The experience of modernity*, Marshall Berman 1988), lending us this idea of complexity as a fluid experience. Space (or territories), and material objects, are transcended by the fluidity of time, becoming less important and less valuable.

The idea of soft or fluid methodologies has been addressed by several authors since at least the 1970s, when Peter Checkland developed the idea of a *soft systems thinking—SST*—as a way of dealing with the complex problems of organizations (Checkland 2000). More recently Koro-Ljungberg (2016) discusses her concept of *fluid methodological spaces* as an exception to linear logic, unbound from stable structures—its purpose *"is not to represent but to resonate and add to reality"*. These methodological spaces *"might also stimulate deeper or more engaged ways to represent, accommodate, and reflect anticipated conditions and preferred spatial dimensions often present in qualitative research encounters"*.

But what design methodologies would stand for "soft" or "fluid"? Non-methodologies, or methodologies without methodologies, as preconized by Koro-Ljungberg (2016), are currently thriving mostly because design became the latest currency for innovative companies.

Design, and most especially Design Thinking, or the designers' mindset of empathizing, prototype and iterate almost risk-friendly (as opposite to the risk aversion on business thinking), has been brought to the centre of discussion in the 21st century innovative, hence competitive—companies. It was appointed by Buchanan (1992) as an appropriate way to approach wicked problems and escalated by IDEO in the beginning of the 2000s, becoming an enormous formula for success to expose the business world to the design mindset and practices. Martin (2009) advocates Design Thinking as a tool for achieving sustainable advantage in business.

This rationale brought up strategic design to the fuzzy front end of innovation, as "the professional field in which designers use their principles, tools and methods to influence strategic decision-making within an organization" (Calabretta et al. 2016). Calabretta and Gemser also state that "Design professionals combine a sense of commercial purpose with a positive attitude toward change, uncertainty, and intuitive choices" (Calabretta and Gemser 2016).

Design became *strategic*, a business and management tool, in the works of Alexander Osterwalder, Sabine Junginger, and others. Verganti (2009) advocates that radical innovation is not only driven by technology, but may also be driven by design, with focus in building meaning. According to him, customers are not only interested in the price or the usefulness of a product, but mostly by its meanings, "function follows meaning" (Verganti 2009). Therefore, design has been brought to business schools around the world by authors as Henry Mintzberg, Jeanne Liedtka, Roger Martin, Bruce Nussbaum, Brigitte Borja de Mozota, Kathryn Best, Hasso Platner, coming from the business world, along with others from a design-related background as Roberto Verganti, Tom and David Kelley, Richard Buchanan, among others.

All this change is typified by the broad dissemination of two models and their variants: the UK Design Council Double Diamond and the IDEO Design Thinking (Figures 2 and 3). Both are not methodologies by definition, although frequently mistaken as, but explanatory models of the design process in abridged form. There are hundreds of tools, borrowed from anthropology, creativity studies, management, marketing, engineering and are associated with these models to translate them into methodological processes. Some were developed by big companies like IBM or Google and have been largely applied in developing initial concepts of products, services, processes, businesses, systems, and policies. One characteristic of these models is that notwithstanding, their representation is somewhat linear, they are essentially non-cartesian, and therefore illustrate the current pervasiveness of soft or fluid methodologies. They also bring a displacement of the design problem from the starting point, as in most traditional design methodologies, to the centre of the process. This movement thrusts design towards a strategic role, situated at the fuzzy front end of product development, the problem is only stated after understanding what the real problem is, not the one at the surface. The role of the user is also boosted, starting from the phases of Empathy (DT) or Discovery (DD), and is now a partner, co-designing and validating process and outcomes, assuming a protagonist role.

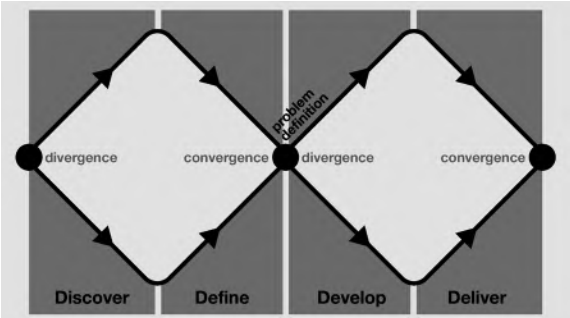

Figure 2. Double diamond model (based on UK Design Council).

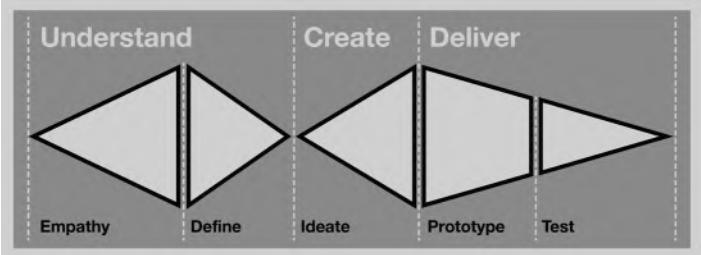

Figure 3. Design thinking model (based on designthinking.co.nz).

A last example towards corroborating these creative-bent user centred methods are card decks and other gamification techniques. Charles and Ray Eames developed a classic example in 1952, the House of Cards—still available at the Eames Office online shop (eamesoffice.com). After a few occurrences in the 1980s and 1990s—as Brian Eno's *Oblique Strategies*, card decks experienced a surge in the 2000s, as reported by Roy and Warren (2019). Card deck tools are *"engaging objects which summarise information, methods, or good practice in a handy form"*, but they can also *"provide structure to a design process"* and even help to *"overcome design blocks"* (Roy and Warren 2019). IDEO has its own Method Cards intended to *"inspire great design and keep people at the center of our design process"* (IDEO 2003). A Designer's Critical Alphabet (Figure 4) is a card deck launched in 2020 by Lesley Ann Noel. As a design educator, she felt *"angry at how identity was erased in the design class even though we talk so much about empathy. I was frustrated having to explain why we had to talk about race no matter what we were designing"* (Noel 2020). The deck introduces critical words and concepts to be discussed by design students as a game, without being a game.

Figure 4. A designer's critical alphabet, by Dr. Lesley-Ann Noel (Photo by L. A. Noel).

3. Product Design Interactions between the Real and Virtual Worlds: Guidelines for Dystopian Interfaces

According to Freire (2011), while symbols (communication) and objects (physical artifacts) were central to the establishment of the profession of the graphic designer and industrial designer in the 20th century, the same did not happen in the 21st century. In this century they gained another value, as they are interpreted as a part of the life experience of human beings and not as mere tools. Thus, design starts to improve the performance of the interaction with products and services through the actions and experiences of users, leaving aside self-experimentation. This fact provoked a new orientation in the field of the designer's actions, directing them to the system, to the forms and reactions of human beings who select and use the products on a daily basis, and not to the products themselves, as was the rule until mid-year of the 20th century.

Currently, the technologies that support Virtual Reality (VR) and Augmented Reality (AR), as well as their potential to improve interactions, are widely known and are already accessible to society in general. However, the current applications of VR and AR are still weak, and their impact is still irrelevant to the current consumption context.

To better understand this situation, we resorted to the strategy of fiction, such as cinema, which over the years presented different forms for VR and AR as common elements of the future that is already present, or that have already become the past. AR and VR were already featured in futuristic productions, some of which were almost 100 years old (i.e., Metropolis by Fritz Lang 1927). Produced at a time when colour television itself was still a dream for most people, cinema introduced AR and VR as an obligatory and common technology. In 2015, no one would think it credible that a holographic shark (AR) would attack Marty McFly in the middle of the street, something that would be unacceptable to many if it weren't for a scene from a 1989 movie (Michael J. Fox in Back to the Future by Robert Zemeckis 1989). In reality in 2015, the use of VR/AR was limited to a few simple applications in advertising and maps via mobile phones, and only in 2016 a video game company launched the first AR application with any social impact (Nintendo Inc., Pokemon Go. Nomura 2016).

The enormous social potential of VR/AR technologies still today, 6 years after Marty McFly's (Michael J. Fox) supposed trip, has not materialized, and there are only simple punctual applications. This leads us to ask the following questions:

- Why are VR/AR technologies still tentatively explored in 21st century society?
- Why are most existing applications below what might be expected?
- Will AR applications ever occupy their space in the real world and are doomed to never leave fiction?
- Is the current technological leap not enough to support everyday VR/AR applications?

Fortunately, the answer to all these questions is the same: No. So why have designers not yet come up with a definitive way to incorporate these technologies into the habits and behaviours of modern society as they did with bakelite (plastic) in the 40s and 50s, with denim and rigid polyurethane in the 60s, with Elastane (DuPont, Lycra®) in the 70s and

80s, with liquid crystal in the 80s and 90s, and with social media in the beginning of the 21st century?

On the one hand, the fact that VR/AR technologies have not yet found their place in the consumer society demonstrates that the development and industrial viability of a new technology, by itself, is not capable of providing changes in consumer behaviour or in society. On the other hand, it proves that Design is an activity focused on interaction experiences and not just on interfaces (tangible and intangible); that it does not create, but that it awakens and guides, new behaviours, practices and consumption habits in a society. In this way, as long as this interaction experience is not identified, no application will be well integrated into society.

3.1 Design is not Done by or for the Designer

According to Flusser (2007), the result of the work of a modern designer cannot be attributed to a single author anymore. Over the last 60 years, industrial production and design itself evolved from an introspective, authorial and almost artisanal activity, to a complex network of processes and methods that feed on different areas, especially society, where the source of inspiration becomes a concrete need of society and not the free abstraction and interpretation of the designer. Therefore, it became necessary to transform design from an individual activity, in the beginning of the 20th century, to a multidisciplinary/transdisciplinary activity that requires work in groups, heterogeneous teams composed of diverse human elements and updated knowledge about the artificial world. Thus, the process of modern design is organized on an extremely cooperative basis (Flusser 2007).

Frascara defines design as an activity that no longer is concerned with the objects, but rather towards the impact they exercise on society, being the objects is just a means to achieve this impact. "We have to stop thinking of design as the construction of graphics, products, services, systems and environments, and think about those as means for people to act, to realize their wishes and satisfy their needs" (Frascara 2002).

Modern Design must be seen as an activity that projects new experiences for products, services and spaces, much more than a common sense that sees it as a simple creator of artefacts (Moritz 2005). In this sense, the temporal distance between the creation and viability of technology such as VR/AR becomes understandable, which can no longer be considered as new, but still do not have a widespread application and acceptance in society. In product design, this incorporation takes place through tangible objects that depend more on understanding their usefulness than on the product's properties or the technological evolution of its materials.

Sanders and Stappers (2008) differentiate design centered on products and technologies (focus on the product) from design centered on the needs of people and societies (focus on purpose). The latter is considered the most emerging, viable and profitable practice in modern design, and the former is relegated to past practices or an amateur understanding of design.

Therefore, nothing could be more wrong than ignoring the effect that design exerts on changing the focus of a society through understanding and studying the needs of society itself and its individuals, making it impossible to change the classic contexts of interaction from a egocentric or even critical vision (Critical of Design), even if aided by the application of new technologies or innovative materials.

At the end of the 20th century, Krippendorff (1989) observed that the most successful design projects were not those that considered people just as "rational users" whose fruit of design is just "things", but rather those that considered design as "social practices", dedicated to the understanding of symbols and preferences, that is, to collective thinking, and which did not belong to the designer, but which were identified and applied by them in a process that was often collective and participatory.

In this sense, society is still waiting for a tangible interface that brings together, with acceptable social penetration, VR/AR as part of a single, useful and viable system. This requires designers to recognize their position before developing proposals for the integration of these technologies that unite two dimensions and two worlds (virtual and real).

3.2 Model for Projects of Products for Mixed Reality

Some elements can be considered essential to design an artifact or system that connects two realities, virtual and real, in the same device, service or interaction environment (tangible + intangible), and that meets the conditions to become socially accepted and occupying irreversible gaps in society.

The model presented by Milgram and Kishino (1994) defines the relationships between real and virtual interfaces (Figure 5), facilitating their understanding. This model encompasses, orders and classifies the interaction environments known so far, identifying their position between the real and virtual worlds. However, the Milgram and Kishino (1994) model does not predict how the real and virtual environments would

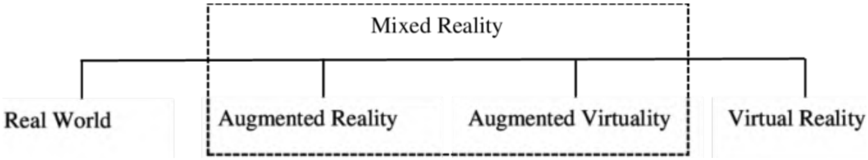

Figure 5. Mixed reality model by Milgram and Kishino (1994).

relate to the artifacts developed in the next 30 years, or how these would be associated with each of the elements of Mixed Reality.

While VR has its interaction completely inserted in the virtual world, AR needs to associate real (tangible) elements with virtual elements in a world that Milgram and Kishino (1994) called mixed reality. This fact makes the interfaces used in AR continue to need tangible artifacts as part of the mixed interaction system. Sometimes these systems act as windows, where reality is mixed with virtuality, sometimes they act with holographic projectors that interfere with reality. In both cases Design is required as it is closely integrated into the creation of experiences in mixed realities. Slowly, the current design of tangible products has presented solutions for the transition from tangible and intangible interfaces. These solutions can be seen in an adaptation of the Milgram and Kishino (1994) model to incorporate the types of applications that technologies such as VR/AR have developed over the years. There are countless ways to mix virtual and real elements, including all human senses. The most common techniques are presented below, focusing on visualization. Thus, it is important to separate VR/AR into three types of interaction with users:

1. **Digital visualization in a real environment:** Insert virtual elements in the real environment so that they are interpreted as concrete elements, seen from the virtual window. Applications normally aimed at appreciating a virtual element in scale and real scenery (e.g., Digital furniture, IKEA; Dimensions of new computers, Apple or projection of virtual dogs in your garden, Google);
2. **Digital complement of the real environment:** generate additional information about real products and elements. Unlike appreciation, usually intended for guidance (e.g., Complementary information on supermarket products Heinz, Amazon AR app);
3. **Digital interaction through the real environment:** Situations that involve the manipulation of systems that work on the real environment. In this case, the focus is on active interaction (i.e., Pokemon Go or Minecraft Earth), where the application performs changes to virtual elements with input from the real environment (i.e., AR Google Streat View; Bosch AR System; Siemens Power Generation Service, Microsoft HoloLens).

From the human senses, Tori (2009) identifies four techniques to mix the real with the virtual worlds.

- **Indirect visualization:** technology that uses the overlap between virtual information and real environment. It is viewed through a screen (e.g., tablet, smartphone). The technology used is the same as the see-through video and in many current applications it is used as a "magic mirror" or window to the Mixed reality, through which the environment around it is observed, as well as the virtual elements added digitally. An example of a product developed with this technology is the "Mixed Reality Book" (Grasset et al. 2007), a real book that, when flipped through, is enriched with virtual information that can be viewed by video see-through or, indirectly, in a monitor. **Advantages:** it has the same advantages as the see-through video and is cheaper and accessible (it can be assembled with common equipment, available at any computer store) and does not require the attachment of devices to the body. **Disadvantages:** it does not allow a direct view of the environment; limited field of view; limited mobility and, if the camera fails, the whole world disappears, not recommended for systems that do not support this type of failure;

- **Spacial AR:** In spatial augmented reality, the virtual enrichment of the environment is achieved through projections made directly onto real-world objects. An excellent example of this reality are the video mapping projections, which democratized and disseminated Mixed Reality. The great advantage of Spacial AR is that we do not need visualization equipment (e.g., head mounted displays, glasses) to interact with the virtual in the real world (Bimber and Raskar 2005). **Advantages:** it does not require the use of devices and can be used with a large number of people (i.e., shows); does not eliminate the direct view of the real environment; and enables mobility. **Disadvantages**: does not control unforeseen elements of the real environment; does not control users' field of vision; the objects in the scene that will receive projection need to be previously modelled and the projection conditions in the environment are extremely demanding; despite its dissemination in the last 10 years, it is still expensive equipment and usually for professional use;
- **Optical see-through:** this technique uses semi-transparent optical devices and, in general, a pair of glasses where it is possible to generate virtual images while allowing the visualization of the real environment over which the digital information is superimposed. An important quality of this technique is that it allows a direct view of real world, without technological intermediation, ensuring greater system reliability and, for this reason, it has been used for work tools and vehicle panels. Another feature is the greater sense of presence in real space as there is no need to correct elements of the real environment such as light and shadow. There are, however, several technical difficulties in this type of solution, such as: the distinction between virtual and real, the difficulties to eliminate from the real world objects that should be hidden in the virtual world (i.e., the projection and calibration of a virtual computer on a table

which, subsequently, a real glass is added at the computer's location, generating the superposition of the computer with the real cup), and the contrast between the quality of images in the real and virtual environment. These difficulties usually lead designers to abandon realistic drawings and opt for high contrast and low three-dimensional interfaces, keeping the two worlds (real and virtual) visibly separated (i.e., google street AR markers). **Advantages:** it does not eliminate the direct view of the real environment. In general, it is lighter and less bulky than helmets used in optical-see-through techniques. **Disadvantages:** low levels pf brightness and an unrealistic contrast of the digital interface, hindering an adequate visual integration of the virtual elements with the real environment and impairing immersion; difficulty hiding unwanted real objects or accurately replacing virtual ones;

- **Video see-through:** It is characterized by the use of glasses or helmets that isolate the users' external vision (head-mounted displays—HMD) and display three-dimensional virtual images (stereoscopic). More recommended for use in VR than in AR because it needs to represent the real world through one or more cameras attached to the user's head (stereoscopic effect) that replace the real scene. It also has the advantage of being able to project the user to another reality, such as seeing the world from a drone miles away or being in a telepresence meeting using a videoconference robot. Here the real scene is captured and blended with virtual elements that are digitally overlaid in real time. The user has the feeling of seeing the real world enriched with digital information and can interact in it, even when physically far away. Some devices allow the user to walk normally through the environment. However, with failures in the display device, in precision, in image quality, or in image capture, the user loses all context of interaction. Therefore, it is not recommended for systems with low fault tolerance (i.e., car driving). **Advantages:** it allows occlusion of real objects by virtual ones; allows control of the real image with contrast, lighting and resolution and can make interaction more immersive. **Disadvantages:** due to differences between cameras and the user's eyes this system can generate many parallax errors; they are not recommended in systems where we cannot lose the link with reality; it usually still has limitations in the field of view, when compared to Optical see-through and does not allow direct view of the environment for unforeseen events (Tori 2009).

Each of these interactions provides a set of requirements that allow us to combine the needs of an understanding of design with the techniques presented by Tori (2009), and with the model of Milgram and Kishino (1994). Figure 6 presents an adaptation of the Milgram and Kishino (1994)

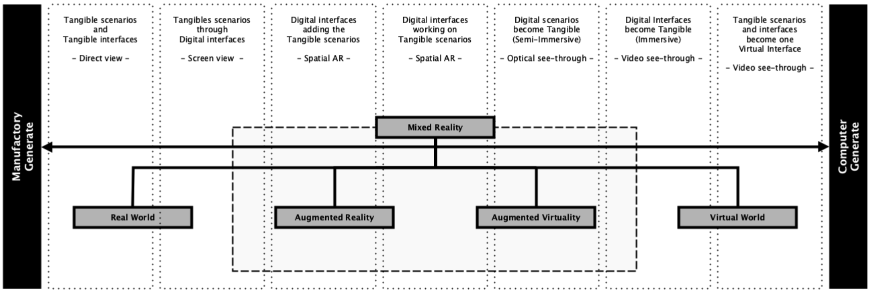

Figure 6. Mixed reality model by the authors (based on Milgram and Kishino 1994).

model where the elements of interaction with artifacts were incorporated in the interaction virtualization process.

At the left end of the spectrum are those applications that do not use virtual resources (completely based on the real world) and at the opposite end are those which are fully virtual, that is, immersive virtual reality systems. Between these two extremes are arranged all the other systems that mix virtual and real elements. In the first range of this core are those systems called Augmented Reality, which provide the insertion of virtual elements in real environments, with a high predominance of the latter.

Based on the classification of artifacts, the following were included in this scenario:

- **Production bases:** for a designer, it is essential to understand the production base for each edge of the chart. For the real world, the classic manufacturing and transformation industry remains, which is responsible for the fabrication of tangible interaction and visualization devices (real windows to the virtual world). In the opposite direction is the virtual world that is completely dominated by applications and developed by the software industry, with a 100% computational basis.
- **Tangible interfaces and scenarios** (Real World): Products that do not have computational elements or software inserted in their interaction. They are usually products with a strong mechanical component (i.e., conventional bicycle) or that have a computer system to control their behaviour but without any exchange of information with their users, keeping all interaction dedicated to the real world (i.e., Segway that uses a system computerized to convert body position into movement and maintain balance control);
- **Tangible scenarios controlled through Digital Interfaces** (Digital Control): Tangible products that can contain computational elements through software, but without any influence from Mixed Reality. These products have their interaction completely dedicated to the real world, but have controls, information and interactions associated

with digital elements present in the artifact, but which do not need to interact with the real world (i.e., smartwatch);

- **Static digital interfaces adding virtual information to the real scene** (Light AR): Tangible products that contain computational elements, controlled through software, that add non-interactive virtual information to real world scenery. These products have Mixed Reality seen through a tangible device present in the real world (window) that can adapt virtual elements to the real environment, simulating virtual products or adding information to the real world. This interaction takes place through the superposition of the physical artifact (e.g., smartphone), which becomes a mobile and optional window on the real scenario (e.g., IKEA's app, Barilla AR campaign, Macbook Apple AR, and WebRTC remote assistance by Mobidev);
- **Dynamic and interactive digital interfaces controlled through real scene elements** (Strong AR): Tangible products that contain computational elements, controlled through software. These products have the Mixed operation with a tangible device present in the real world (window), and use the real environment or elements of it to generate a virtual interaction through real world elements. This interaction takes place through the overlay of the physical artifact (e.g., mobile phone), which becomes a mobile and optional window on the real scene and an application that constantly updates its information according to the interaction with the real scene (e.g., Google AR Street View; Pokemon Go, Minecraft Earth);
- **Dynamic and interactive digital interfaces that become part of the real scenario** (Deep AR): Its difference with the previous item is made only by changing the control interface, which remains tangible but leaves it as a mobile and optional window for the user. At this level, the interface occupies the user's entire field of vision, reacts to real-world stimuli, allows virtual interaction, but invasively occupies reality, through transparent devices that project digital information on real environments such as panels, glasses and other devices that occupy the entire field of view (e.g., Volkswagen ID.4 AR HUD, Siemens Power Generation Service, Augmented reality solutions by SRI International, Microsoft HoloLens, and Apple Glass);
- **The interaction interfaces and the real scenario become elements of the virtual world** (Deep AR Light VR): At this level, the interface occupies the entire field of vision of the user, reacts to real world stimuli, allows virtual interaction, occupies the reality in an invasive way, and reality itself becomes digital through an image of reality projected through a camera. The devices are opaque and replace the image of reality with an image collected through a digital image. In

this context, the difference between AR and VR is given exclusively by the real-time projection of the user's field of view (AR) and the projection of another scenario (VR). Despite being more advanced in spectrum, this dimension has more active products on the market than the previous one (e.g., Oculus HMD, HTC Vive);

- **Interaction interfaces and virtual scenery become the real world** (Deep VR): At this level, the interface occupies the user's entire field of vision and reacts only to physical stimuli from his real body. The user is the only element present in the real world, all interaction is virtual and invasively occupies the real world. Reality itself becomes completely digital. Here only VR can be considered, bearing in mind that the projected scenario may not be the same as the reality in front of the user (through a camera applied to a device, such as military drones or surgical robots), or a virtual simulation through a digital world (as in Videogames and virtual applications of remote visits to museums). The devices are opaque and completely replace the user's image of reality by an image of another reality or fiction (e.g., Military Drones, RoSony RV, Caves, Telepresence robots and others).

The methodologies developed for product design in the late 20th century have predicted the transfer of tangible interfaces for the immaterial world, since the interpretation and the proper placement of roles during development (producer, product and penetration) and the sources of information collected society were taken care of. In this sense, it is acceptable that the Tangible Product Design of the 20th century ceases to exist as we know it, and that the 21st century brings the universal recognition that, for design, the tangible and the intangible coexist harmoniously in the element that we will continue to call it "consumer products".

Findeli (2001) predicted that the 21st century would witness a profound change in the industrial and design processes, not so much in its manufacturing, but in the production of intangible and dystopian products that will shape and condition our daily lives. According to the author, this change will be above all epistemological, resulting from a change from a society based on the consumption of material goods to one that consumes intangible goods, implying new responsibilities for the designer. The designer's task to create tangible artifacts no longer needs to be taken for granted, in a world with complex and dystopian systems designers are expected to act more than do "things". This means to say that the design project is ethical, not technological and that only in this way, it recreates the world (Findeli 2001).

4. Utopies, Dystopies: How Wicked Problems are Paving our Way and How Design can Contribute to Reshape Things

The complexity of social problems faced by both public and private actors has escalated since the second half of the last century. Economic growth in the post-war period led to an increase in household consumption, generating a consumption surplus and consequent problems in environment, housing, education, health, and urban mobility. In the southern hemisphere, rising levels of income inequality and social precariousness, in addition to political turbulence, have raised the level of urban violence and the impoverishment of underserved populations, plunging the region into religious and ethnic conflicts, further to terrorism and drug trafficking. In the second decade of the Third Millennium, such problems spread on a global scale, affecting countries hitherto considered immune. Deindustrialization, as a result of the global contraction of economic activity, associated with the digitalization of the economy provides a continuous decrease of employment and income of population contingents that previously were part of the regular workforce. Contrary to the current discourse that automation leads to unemployment, Benanav (2020) argues that it masks the effects of the global economic slowdown, the real cause of the problem.

Therefore, we are in a world where turbulence and uncertainty are the rule, and no longer the exception. Some call this world VUCA (Volatility, Uncertainty, Complexity and Ambiguity) (Bennet and Lemoine 2014), others identify it as BANI (Brittle, Anxious, Nonlinear and Incomprehensible) (Cascio 2020). Thereafter, designers and public policy managers are urged to offer solutions to increasingly intricate and multidimensional problems. Such complexity is related both in number and in the diversity of agents involved in the situation, which can be of different natures: human and non-human, public, private or mixed in nature (Conklin 2006).

For example, we are currently experiencing the problem of global warming, which leads us to discuss as a solution the reorganization of economic activity in favour of sustainable solutions, in addition to the need to reduce the pace of current consumption. However, thinking *degrowth* of consumption and living standards as a solution does not elapse from a change in people's lifestyles. It comes from the continued reduction in global economic activity—which has frightening impacts, since Western societies were structured throughout the 20th century from the tripod of job/income/consumption.

Deindustrialization of the western world, associated with the digitalization of economy, accelerated by the Covid-19 pandemic, exposes the fractures of a highly complex scenario. A new social class, called *precariat*, composed of unstable workers who obtain their income from digital platforms of the access economy, densifies daily by structural unemployment in the industrial economy (Standing 2011).

In this "hot, flat and crowded" planet, according to Friedman's metaphor (2008), the linearity of the solutions proposed by social planners is insufficient to face the growing instabilities and uncertainties in the contemporary world. The classic planning model, created in the context of the industrial era, associated with analytical thinking, seeks solutions based on a linear and sequential vision that aims for maximum efficiency. The mechanistic view of nature, disseminated by hard sciences and engineering, turns out to be unfeasible given the peculiar complexity of the social problems we face today.

Issues such as global warming, pollution and mobility in large cities, together with the explosion of racial conflicts in the peripheries of American cities, made it urgent to develop a framework to deal with these problems. During the 1960s, philosopher and NASA consultant West Churchman organized a seminar in Berkeley aiming to discuss how the US space agency's problem-solving methodology could be applied in the universe of social problems. In one of these sections, Horst Rittel, a German design theorist and professor from the HfG Ulm, presented a list of differences between social and scientific problems, pointing out significant contrasts. After his presentation, Churchman commented that social problems, given their complexity, sounded as if they were *wicked* (Skaburskis 2008). According to Churchman:

> "'Wicked problem' refers to that class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system and thoroughly confusing. The adjective 'wicked' refers is supposed to describe the mischievous and even evil quality of these problems, where proposed 'solutions' often turn out to be worse than symptoms (Churchman 1967)."

Six years later, Rittel formalized the concept of *wicked problems* in a seminal article, inaugurating a whole line of investigations regarding the resolution of multidimensional problems, of high social complexity, whose boundaries between right and wrong are difficult to be determined (Rittel and Webber 1973). In this, the authors affirm the need for a different look in facing social problems:

> "By now we are all beginning to realize that one of the most intractable problems is that of defining problems (of knowing what distinguishes an observed condition from a desired condition) and of locating problems (finding where in the complex causal networks the trouble really lies) (Rittel and Webber 1973)."

For Rittel and Webber (1973), society's problems are intrinsically wicked, since they are difficult to be clearly defined and, one of their most important characteristics, are never solved—at best, they are minimized, displaced, reduced, being continuously re-solved. Buchanan (1992) argues that every design problem is wicked—and the exceptions are those where the wickedness has already been taken out—and therefore design thinking is the perfect tool to approach wicked problems.

Conklin (2006) systematizes the characteristics of wicked problems:

***"There is no definitive formulation of a wicked problem"*:** Unlike structured problems, the information needed to understand wicked problems is not found before their solution but emerges during the solution process itself. Successive attempts at resolution assist in their understanding, being a continuous and cyclical process of (re)formulating insights. This makes understanding the problem and seeking solutions concomitant.

***"Wicked problems have no stopping rule"*:** As there are not enough ways of understanding the problem, wicked problems are never definitively solved. On the contrary, the solutions presented are open-ended, being searched and reworked. In addition, new insights are generated from the moment solutions are implemented, enabling the emergence of new aspects of the problem that have not been considered before, further understandings and improvements. As stated by Burge and McCall (2014), there are no categorical and objective criteria that points to a unique and definitive solution. Often the solution process comes to an end with the exhaustion of financial resources, time or energy of those involved.

***"Solutions to wicked problems are not true-or-false, but good-or-bad"*:** Due to the previous characteristics, we can only propose solutions that are considered adequate, satisfactory or sufficient. Such problems, in this way, place us in the scope of the moral dimension, a reflection that is little explored in the literature on the subject. Therefore, the search for solutions needs to involve an appreciation of the multiplicity of legitimate interests of the actors and stakeholders involved, since some proposals may favour some agents to the detriment of others (Wexler 2009).

***"There is no immediate and no ultimate test of a solution to a wicked problem"*:** For this category of problems, the implemented solutions generate effects over time, which may be favourable or unfavourable. A chain of future consequences is generated from the solutions presented and implemented, requiring the problem to be worked on again and again (Burge and McCall 2014). Therefore, the process of implementing solutions to a wicked problem is recurrent and continuous, requiring constant monitoring of both the social context and the stakeholders involved in the situation.

***"Every solution to a wicked problem is a 'one-shot operation'"*:** This is one of the most important features of the wicked problem resolution process. In general, every solution brings consequences, which can be positive, negative or even unexpected. In addition, they can generate new problems in the future, which will need to be addressed later. Generated solutions provide irreversible impacts on the problem itself, changing, displacing and reconfiguring it. Hence, the need to think about all possible developments of each solution formulated, in order to reduce externalities and unexpected effects.

***"Wicked problems have no given alternative solutions"*:** They are inexhaustible and can be split into minor or subsidiary problems. Ergo, there may be a set of potential solutions that have not yet been anticipated, which will only be able to be envisioned after the implementation of the first solution. Hence design thinking, due to its iterative characteristic, empathy with the agents and stakeholders involved, and creativity may be drivers in the process of generating solutions.

***"Every wicked problem is essentially unique"*:** The more solutions formulated, the greater the understanding of different angles of the problem occurs naturally. Wicked problems are essentially dynamic, undergo changes during both their resolution and monitoring. Because they are unique and distinct, there is no wicked problem like the other, which prevents your resolution process from being reduced to some kind of algorithm. This does not mean that lessons learned cannot be used from one problem to another, but such a transfer must be viewed with care given the unique character of each situation. For example, the dilemmas of urban mobility in one city are never equivalent to those found in another, no matter how similar they may be. This is one of the main problems observed in the last decade with the spread of design thinking in different areas, such as project management, business and public administration.

***"The existence of discrepancy representing a wicked problem can be explained in numerous ways"*:** Multiple solutions can be devised to solve these problems, making the process open and continuous. Solutions to a wicked problem are never exhausted, given the universe of possibilities that result from both the complexity of the situation and the interaction of human and non-human stakeholders. Several paths can lead to the same place in the search for solutions, which never runs out after the process has ended.

***"The designer has no right to be wrong"*:** This last point returns to the question of the moral dimension of the whole process of coping with wicked problems. Multiple agents, the diversity of interests, the dynamics of interaction between the stakeholders and the changing scenario make it even more important that the designer understands that any proposed solution will have a moral impact on everyone involved. Every proposed solution to a wicked problem has ethical and political consequences, which must be considered and discussed constantly.

This last point deserves a development: As the wicked problems never end, we (and the next generations) will have to face them in their new versions and modalities. Wexler (2009) points out four moral dimensions that the designer deals with when facing wicked problems: *rising expectations; risk of false security; sense of urgency;* and *confusion about the proposed solutions.*

First, the ***raising of expectations***, given that they provide experimentation and the adoption of innovative or disruptive solutions, both on the part of their proponents and the agents impacted by it. The danger of naive, costly solutions or even with harmful consequences is quite high, and the designer must constantly stick to possible negative externalities or future implications that harm some agents to the detriment of others.

The second aspect, which is directly related to the first, is the ***risk of false security***, given that designers can lead the actors involved to take high risks by promising deliveries beyond the feasible. This is not to say that designers necessarily induce users to take exaggerated risks, but naive interventionism full of good intentions can be quite harmful in the future. However, when facing wicked problems, designers are always affected by the risk of *iatrogenesis*—literally, the damage caused by the solver—when the impacts caused by a solution are greater than the expected benefits. Hippocrates' ethical principle (*"primum non nocere", first, do no harm*) should guide the moral horizon of the designers' work. This is one of the central points of Taleb's (2010, 2012, 2018) work on the *naive interventionism* of designers and policy makers in proposing solutions to wicked problems—ignoring potential risks and damages of their proposed solutions. Several examples of naive interventionism are accumulated both in the economic literature and in the scope of public policies: economic crises, disorganization of urban mobility, degradation of urban areas and impacts on the environment are not only the result of unscrupulous agents, but also the result of interventions whose risks have been undersized.

The third is the ***sense of urgency*** that affects everyone involved, given the critical nature of wicked problems, which require urgent solutions. Actors who manage to articulate politically more efficiently are able to attract more attention to their respective agendas, bargaining attention from designers given the greater visibility that results from their higher ability to articulate and negotiate. Such a process can lead to neglect of other actors involved, due to low social visibility, inefficiency of their lobbying process or even its low representativeness in relation to the whole situation. Designers must be careful that this sense of urgency does not lead to a decrease in the capacity for critical judgment during the formulation of solutions, or neglect during the stages of monitoring the solutions. The *"cry wolf syndrome"* should not be an excuse for neglecting or transferring risks to the parties involved who have a weak or less visible political organization (Atwood and Major 1998).

The fourth and final moral aspect of wicked problems concerns the ***confusion over the solutions proposed*** by those responsible for solving them. Since wicked problems have no definitive solution, designers must deal with the dangers of anxiety in order to resolve them efficiently and quickly. Moral issues such as the accountability of formulators of solutions that increase the risk for the actors involved, the excessively high expectations of delivering solutions beyond the ability to formulate them, as well as the scrutiny of the academic and professional community of designers in the sense of monitoring the training of professionals who will work to face wicked problems, in addition to developing new methods and tools that reduce the damage of exaggerated interventionism, are urgent on the agenda of public design policies (Wexler 2009). Transparency and accountability, therefore, must be the central guidelines in the performance of designers and managers of public policies in facing wicked problems.

Designers and public policy makers need to be careful not to succumb to the temptation of the Procrustean Bed, which is to adapt individuals to their bed. Like the Greek King Procrustus—who, in his eagerness to fit visitors to his bed, cut the limbs of the larger and stretched the smaller individuals, one must avoid instances where problems fit solutions, and not the other way around. The Procrustean Bed, in this way, reminds us not only the limitations of human knowledge, but also the potential damages and risks involved in the solutions proposed by those responsible for solving them. We must resist both the dangers of over intervention and the neglect of sub intervention.

The aggravation of the problems we face today both on a global scale (global warming, de-industrialization, ethnic or religious conflicts), and national and regional (urban mobility, housing, unemployment, urban violence, among others) greatly increases the risks that we face. This aspect from the throes of modernity has been described by the social sciences as the "risk society" (Beck 1992) or the "time of catastrophes" (Dupuy 2002). In recent years, the spread of automation and digital technologies embodies a growing trend that problems arising from social complexity will be solved by collecting data from citizens and users, using big data and machine learning tools, providing public policies based on analytical evidence from rational interventions. Would we be entering a new era where wicked problems would finally be tamed from an absurd amount of data captured from digital devices located on cell phones, automobiles, objects, clothing or even implanted in humans? Would we be living in a new "end of history", where finally the fuzzy character of social complexity would be solved using data and analytical tools for producing information? Are we, therefore, at the dawn of a new era, marked by the technological utopia of digital rationalization and big data? Would we finally see the wicked problems eradicated from our social fabric? What is the role of designers and managers in public policies in this new scenario?

Head (2019) points out the dangers of this evidence-based approach to solving social problems. The question to be debated is: to what extent would such a rationalist and analytical view of social problems promote a narrow and inadequate view of social issues? In short, what are the dangers of evidence-based interventionism in the face of growing environmental, social and technological problems?

First, it is important to understand that any technology, tool or action methodology has positive and negative aspects, that is, they have risks and opportunities. In case of the ongoing digital transformation in Western society, and accelerated by the disorders arising from the pandemic, the dangers are numerous and have been exhaustively debated in the last decade by a plethora of specialists from different areas of knowledge (Harari 2018). Exhaustion due to the persistence of wicked problems, as well as the urgency of their solution, places us in a dangerous zone where harmful effects and negative externalities can be dangerously neglected. It is up to designers to warn about the dangers of reductionism and easy solutions of a technocratic nature when facing wicked problems. As Conklin (2006) states:

> "You don't so much 'solve' a wicked problem as you help stakeholders negotiate shared understanding and shared meaning about the problem and its possible solutions. The objective of the work is coherent action, not final solution."

The attempt to domesticate wicked problems, based on promises from digital data analysis and evidence tools, provides a dangerous increase in naive interventionist solutions. Voluntary interventions in the social fabric that, as if by magic, would solve all the complexity of social problems bring us much closer to *dystopian* scenarios than *utopian* ones. This is the core of Beck's (1992) argument when pointing out the accumulation of technological and environmental risks that would give rise to catastrophic effects for our civilization. By dystopias, we understand catastrophic visions of the future, which in recent decades have become quite present in popular culture, both in environmental, nuclear and biological hues. Contemporary cultural productions are replete with alien invasions, zombies and non-human agents of at least dubious character. Once circumscribed to the action of human agents (through wars, terrorism, global warming and environmental collapse), the current dystopias reinforce our species' sense of vulnerability and anxiety. The two main strands of current dystopias come from the replacement of our species by intelligent automata, making us irrelevant and condemned to idleness, or the eradication of our species by some external biological agent (Harari 2016, 2018). The current pandemic event is clear evidence of the precariousness of human civilization, causing economic, political, social, cultural and mental upheavals that will have lasting effects over the next few decades.

Dystopias are not exactly new in the history of our species, going back to the beginnings of human civilization, initially linked to eschatological and catastrophist religious myths. In recent decades, however, the current dystopias are fuelled by a secular pessimism that is installed in contemporary society given the increase in risks and the worsening of social problems, both in scale and in complexity. The word comes from two Greek terms, dus and topos, meaning sick, bad, or unfavourable place. Dystopias are not necessarily linked to fictional scenarios, and may be anchored in reality, since they are related to a vision of the future in which chaos, ruin and destruction prevail (Claeys 2017).

The current scenario of social problems we face has a feature in common with the wicked problems: it does not admit a stopping point—there is no way to go back to an idyllic and orderly previous state. We are prisoners of our time, and it is natural that we romanticize the past, finding it more organized and less unstable. Our diffuse sense of widespread anxiety is due to the realization that not only social problems are not effectively resolved, but they are becoming increasingly threatening. The sources of dystopia are numerous today: political (the rise of totalitarian governments), environmental (irreversible climatic damage to our planet), biological (the Covid-19 pandemic, for example) and technological (with science and technology imposing an unrestricted surveillance society, about to destroy us). Invariably, dystopias are the result of utopias that failed terribly, by generating disruptive negative externalities that alter the current state of affairs.

In a post-pandemic scenario, we are currently experiencing one of those decisive moments in the history of our species. The social divide imposed by the digital acceleration, in addition to the drastic reduction of the current economic activity, leads us to a scenario where utopian and dystopian vectors coexist simultaneously. On the one hand, there is a digital plutocratic elite that invests in the domain of life and in the construction of rockets and space stations, seeking refuge in idyllic planetary resorts, far from the chaos and ruin of planet Earth. On the other hand, the huge mass of digitally excluded people, made up of idle individuals, precarious in occupations that barely make basic subsistence possible, try to survive in the chaos and dystopian disorder of a hot, polluted and highly populated planet, where the health conditions and dignity are getting worse every day. This is the crossroads where designers, managers, and public policies meet at this moment: having to choose between two divergent futures, one utopian and the other dystopian. Basically, utopia and dystopia have closer relations than we imagine, since they inhabit a continuum of escalating states between extremes of possible futures, which are not completely feasible, but which exist in potential.

The 20th century was a period of excess economic activity, income and consumption. Looking back, it is an idyllic and utopian century. However, the seeds of dystopia were present in it, and have become more complex over the decades. Nowadays, designers and public policy managers need to deal with a post-material society and a post-excess economy, where work will no longer occupy the central axis of human existence, as in the last century (Inglehart 1977). The frontier that separates utopia from dystopia goes through the recovery of dignity, autonomy and the purpose of human existence. This is the task of designers today: in the complex world of wicked problems, they need to assist in the process of conceiving new anti-fragile life forms, which improve with chaos and instability, instead of avoiding them using quick solutions, high risk for those involved and with heavy costs for future generations. This is the wicked problem that we, and future generations, must relentlessly face, as the survival of our species depends on it.

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5

Voyeur-Voyager @ AR
Theory, Concepts and Promises of Augmented Reality as a New Medium

Herlander Elias

1. Introduction

Augmented Reality (AR) as we know is three things; first it is a metaphor for an "extended space" in connection with our primary reality, which is the real world; secondly, AR is a form of interfacing with digital information while being in touch with the real world, it is a model of dealing with data at the same time as some other task is being performed; thirdly, last, but not the least, AR is an emancipation from Virtual Reality (VR), from which it borrows certain ideas. We shall explain these three models altogether. AR has existed since the 1970s in the military, especially in realm of the jet-fighters interface of vectors and altimeters and target trajectories for engaging enemies on airspace, for example in aircraft such as the Northrop Grumman F-14 "Tomcat". In this circumstance the pilot could fly and at the same time information needed by the pilot would show up on a glass above the cockpit panels, all while pursuing an enemy in mid-flight. Ever since then AR has become the norm in cockpit interfaces for military pilots. Now we have it on our smartphones by using the cameras for AR apps and games, but still, the data is overlaid upon a primary visual field. This is the premise. Beyond this, AR has become an interface, a model of inspirational designers that think that both in driving, walking, or in

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sports, the AR interface is as helpful as talking to the Google Assistant. But the AR interface seems more futuristic and future-proof. Now, all this makes sense because there has been something since the 1990s called VR, but the problem with VR was the interface. VR had hardware like smart gloves, headsets and even gaming consoles but the concept never took really off because there was a lag and because it relied on a smartphone, a PC or a console. Whereas on the film studios, motion capture and VR are useful for directing actors who become digitized and their avatars interact with full CGI (Computer Graphic Images) worlds. In this context, we aim to theorize AR as a new medium, and we shall speak about the ideas and models that paved the way for it to become a driving force, powerful enough to attract brands such as Apple and Google to it.

2. Context

For a start we should ask ourselves the question: "what is Augmented Reality"? and from authors such as Shedroff and Noessel the answer we get is pretty straightforward; they say "The information should 'overlay' reality" (2013), which means that whatever the user is doing, AR is a supplement, not the primary thing, it is always a second thing acting upon primary reality, hence the name "augmented". Back in 1998, Michael Heim stated that AR is "The superimposition of computer-generated data over the primary visual field. (...) the jet-fighter's heads-up display is an early form of an augmented reality". And he is right about it. We can say that AR is, much like the computer, VR, the Internet, and the GPS, a military designed interface. It makes so much sense that the cutting-edge Joint Strike Fighter Lockheed F-35 uses such an advanced AR in the pilot's helmet, that its cost is something around 40.000 USDs or more. What we are saying is that AR is a military-driven interface, its origin is military and as for its future it may go mainstream, thanks to the endeavors of Apple, Google and other tech giants. One author from Interbrand, who holds a prominent position, Jez Frampton, believes that these days everything has a digital strategy. He also believes that the revolution is based on the fact that the touchpoints of brands will be digital or digitally augmented (2012). So, we could say that one way for AR to go mainstream is to be adopted by interface designers working for brands, especially the tech giants. Kapferer, for instance, assures that some brands turn their products into something inevitable as "an augmented product" (1991). We may infer that, if AR is to go mainstream, this type of interface will turn everything into an "extension", all things will become an augmented product, should the tech giants succeed with the right combination of light and fashionable hardware and futuristic software into an easy-to-use interface.

Brazilian author André Parente speaks of a "geometrical gaze" (in Parente 2004). And what we have here with AR if it takes the form of smart glasses mostly, is exactly the exacerbation of this geometrical gazes, as the user of AR interfaces will look at his surroundings and find useful information in 3D on top of his primary field of vision, much as the smartphones and their cameras enabled with time-of-flight sensors already provide. But considering that AR is a military interface, that even shows up in some videogames as a sort of model for the future of warfare, we must accept that somehow AR will cement this idea that there is "an armed vision" (Crandall 1999). Videogames and VR in general continued this path, but AR is more promising because it could go mainstream more easily as Pokémon Go players know very well. According to this it seems that where VR failed to go mainstream, AR might succeed, because the conjecture is technologically more susceptible for change and the online and digital community has grown exponentially. In one particular book, theoretician Karin Hoepker says she believes that we are living a "post-science fiction agenda" (2011). The reason for this is simple. Science Fiction (SF) stopped worrying about the future or depicting it. It now focuses on the present. Also, if there is such a thing as an SF agenda, we live in a time in which technology is already so futuristic that there is nothing about it that seems odd. On the contrary, we have embraced technology, from computers to cloud computing and smartphones, and all of this sets the stage for AR to mean the emancipation of interfaces. AR represents the next stage for dealing with information-rich worlds. Much like Hoepker we have to agree that AR seems to be next step in interface design, from simple apps, to gaming, and more. Should we narrow AR to some simple features, we have to follow Shedroff and Noessel, as they claim that AR is about "sensor display, location awareness, context awareness and goal awareness" (2012). Beyond these four categories, a translucid vision is achieved. And this is the futuristic look of AR, it is something else we do beyond interacting with the real world. It was never meant to be a replacement, unlike the futuristic visionaries claimed about VR and what the Science Fiction writers said.

Jacques Rancière enjoys discussing our relationship with the "spectacle", the model of viewers' vs participants. He affirms that we need a theater where the optical relation—implied in the word *theatron*—would be revolutionary. For him what is required is a theatre without spectators, where those in attendance learn from as opposed to being seduced by images; where they become active participants as opposed to passive voyeurs (2009). And here we have a good concept to start: "voyeur". What once was a negative condition of a passive mass media audience is now rendered as a starting point for new interfaces. In the AR context, the user should be both a voyeur and a voyager as well. He shall interact with data and disclose information by dealing with good interfaces specifically designed for AR smart glasses or headsets if that is the case to be. It is as if the spectacle of the digital world that once was called "cyberspace" by William Gibson in 1984 is to be empowered and evolving into something more. Author Julio Plaza in 2004 spoke of "Third Generation Images" (in Parente 2004). Perhaps these next-generation images triggered the emergence of AR. After all we need not images to be seduced by, but rather images that respond, thanks to responsive design, to our commands. It is like merging the optical world with the cyber-data world. And from this mash-up AR surfaces as a new medium, something that discards the usage of the computer as the box we have known for the last four decades. However, with AR, not only are we voyeurs, but we are voyagers as well. This condition of "voyeur-voyager" in AR is promising because the next generation images become more accessible and also because CGI and interface design made it possible for "meta-images" to exist (Julio Plaza in Parente 2004). These images that are something more, that go beyond traditional footage and prove that we are before a new kind of subject. The user of AR is being interfaced. Well, if in VR, like Couchot affirmed, the "interfaced subject is more traject [path] than subject" (1998 translation is ours), then in AR the same thing applies, since we need AR to overlay our primary visual field with data. AR is something that augments, it extends the computer world on top of the real optical world. Hence the subject is a new kind of user.

Jacques Rancière (2009) spoke of a "new topography of the possible". That is exactly the aim of AR. It's about new space, or "dataspace" over the real space. And in this new topography of the possible, actually anything is possible since the user is not forced to disconnect from the real world, unlike what happens when one interfaces with VR. Virtual Reality was meant to be a replacement, a substitution, but AR is meant to extend, to be simply more. If we look carefully at the real reason why "cyberspace" was envisioned the way it was we understand how it differs from AR. William Gibson says that cyberspace was about interface design, but above all an "imaginary narrative space" (in Neale 2000), in which the action could unfold, yet in Gibson's model VR/cyberspace was meant to be an alternative digital world. AR, however, is not supposed to replace anything. It might actually help us emancipate ourselves from the computer as a device into a straightforward interface based on cloud connection. Personally, I believe that this is the age of a "continuous geography in digital media" (Elias 2013), because there is an optimization going on that ends all differences on behalf of the pure interface form, we want to throw away the cables, go wireless, and also terminate the heterogenous file types. We want the digital world to become a simple single thing and not a mash-up of many different things. Much like the smartphone represented inclusion for people who never used a computer, AR gear might begin the trend of connecting people that never used a computer and that do not want to use a smartphone for everything. Nevertheless, the problem is always the optical model, because whether it is the computer, the tablet, the smartphone, and headset or smart glasses, ultimately, we are still relying heavily on screens, even if they are translucid as the jet-fighters military pilot helmet with AR-enabled. Should AR go mainstream and we will have a new model worth using for communication, for stories and brand connection, a true challenge for designers of interfaces. Like Kelly, we are forced to accept that, "Those stories will play across screens. Everywhere we look, we see screens" (2016). And there is a reason for this, one that Manovich defends: "We still have not left the era of the screen" (2001). The smartphones and tablets we use are a proof of this. But other authors, like Simon Bond, follow the same direction:

> "Screens surround us—they're on our desks, in our laps, in our pockets. They're in airports, on airplanes, in cabs, in grocery store aisles, and on gas pumps. We're entertained by them, informed by them, challenged by them, connected by them. We watch them, write on them, work on them and play on them" (2012).

Based on this, we assume that screens are prevailing. So, what are the challenges for AR? Well, AR must succeed with screens or beyond them. Smart glasses and headsets are the most plausible forms. Perhaps glasses are the best model since they allow us to interact and see data while we walk, run and drive. And since the purpose of AR is to augment reality, it cannot work out as a replacement at all. However, we are still dealing with screens, even if they are translucid screens. Glass technology plays a key-role here. One thing that psychologist Sherry Turkle (1997) got right regarding VR is that she claims that VR is not real, but it has a relationship to the real. Where AR emancipates itself from the VR model is that it is not supposed to be based on scenarios, it is based on infographics and data, responsive design and icons. If in VR, our body was our password, our digital identity was "us" (Kelly 2016), in AR "our" world is our password, and our moves are what we are. And we are a voyeur-voyager. We see, we go for a stroll, we drive, we play, and we handle information.

Back in the 1960s, Marshall McLuhan spoke of a "vivid interaction" (1994). What we are pursuing with this theory about AR, is to figure out if this concept of vivid interaction, which failed in VR, is actually going to happen in AR. After all, VR promised to be an "enhanced environment" (Turkle 2011). And it failed. It looks good on science fiction films, but since we are now dealing with a post-SF agenda, the fact is that the enhanced or extended environment is more likely to take place in the interface design of AR applications, and also for tasks of everyday use. McLuhan at his time said that "The visible world is no longer a reality and the unseen world is no longer a dream" (1994), because his enemy was the alienating world caused by mass media TV and commercials. The problem is TV did not die. It resurfaced as a Netflix streaming model and as YouTube. Following this, we could say that although there is the danger of ourselves becoming passive spectators before screens, the promise of AR means that the passive role of the user might be reversed, exactly because this user is an emancipated and empowered user. VR was based on representation and constructs, while AR is based on extension and awareness. The subject is still supposed to be engaged, but not in a disconnected way from reality, as VR promised. Turkle says that we become what we play (1997). And all the players from Pokemon AR games are becoming something else more than just a player, they interact with the world, they left the couch. According to Maarten Lens-Fitzgerald, AR means:

> "Any surface with any content, any shape, any form, will be recognizable by head mounted displays and other mobile devices. And all will be augmented with ID information such as where it's from, who owns it, what is around it, what others think of it, what happened to it, what is connected, what is its status, and where you can get more" (in De Waele 2013).

In this new model, AR is a breakthrough, exactly because "As its name suggests, AR is about augmenting reality, not replacing it" (Shedroff and Noessel 2012). Maarten Lens-Fitzgerald believes that this will be either a very functional display of information and interactivity or it will be 'marked up' with media and design for a more engaging experience (in De Waele 2013). The whole concept of an engaging experience was already present at VR, but the hardware and the software combinations were never smooth. There was graphical lag, or interference or just the need for bulky gear. AR is technology that augments a user's perception of the real world, with useful, data (Shedroff and Noessel 2013). In Maarten Lens-Fitzgerald's perspective, AR means that: "The key part of the medium will be out of the box. (…) It will be on the packaging, on the jacket, on the wall. It's projected through your lens or glasses on 'it' or the reality itself is a display. It's all around you" (in De Waele 2013). In sum, whatever the gear for AR we will use in the future, the most likely interface will involve a translucid screen, a clear field of view, data overlay and the interface will not be based on readability or the manipulation of the representation of the world.

3. The Cybernetic Imperative

The cyber-part of AR, the cybernetic imperative, means that most of the ideas for AR came from the vision we had from the previous model of digital world interactions, which in this case was the VR and the cyberspace model. Though, in the 60s McLuhan already spoke about the so-called "electric environment" (1994). And somehow, without the full-blown Internet of our days, McLuhan understood that whatever the future could hold for us, there would be something electric, which we could adapt to electronic. This tells us that AR is the apex of the electronic world, the paramount of the cybernetic imperative going beyond traditional computing. What keeps driving the digital media future is "the cybernetic imperative" and control, as Mark Nunes explains (apud Nunes 2011). We need AR because we could in specific tasks or games or utilities control things better without pulling out a computer or a smartphone. In the future even a tablet will seem outdated. Back in the 60s, McLuhan said that "Once a new technology comes into a social milieu it cannot cease to permeate that milieu until every institution is saturated" (1994). It begins to seem true. As the tech giants face a post-smartphone world, a world in which an iPhone is no longer a novelty, AR appears to be the next step for information display and computing, digital interactions and gameplay. AR is designed for the user that is also a consumer. Brands that now advertise on Google will cross the Google Maps frontier and show up on our smart glasses since the AR model follows context awareness and goal awareness. We know that "Consumers are multichannel, with and without the Internet" (Fred J. Horowitz in Meyers and Gerstman 2001). The question is that within this cybernetic imperative the computer/network/smartphone/cloud will become one single thing: an augmented space, one augmenting medium. In a discussion regarding the Internet, author Nicholas Carr says that "The medium is not only the message. The medium is the mind. It shapes what we see and how we see it" (2008). Of course, Carr was not speaking about AR, but he notices something that matters to us. When McLuhan claimed that "the medium is the message" (1994) at his time, he meant that each medium formats its own message in its own way. The question, thus, is not the message but the media instead. This means that MTV is the videoclip, TV is the news and Radio is the talk show. As for Carr's arguments, since he says that the medium is not only the message, the medium is the mind, and considering that McLuhan envisioned media as extensions of man, we are led to believe that today's media like AR are based also on extension and augmentation. There was a time in which "Futurity" (Gibson 2012) was the word for describing things yet to come. AR's interface elements are more than a depiction of the future. They represent extension and an augmented reality at its best, a promise fulfilled. When Gibson speaks through his characters in his SF novels and one of the characters says that he has a "post-geographical feeling", something that Gibson himself feels (in Neale 2000), it means that the media of the future will be more than just a global network or an ever-present form of cloud computing. The future, or better rephrasing, our current present in the post-SF agenda, means that being always online and relying on a constant global linkage will require a new interface. And this is where AR comes in. It represents a new stage, the next stage. Not only for ourselves to deal with data, but also for the world and social networks, and many other applications, to interface with us in a more subtle, smooth and uncomplicated manner. Dave Burwick thinks that it is all about "interfacing with the consumer" (apud Meyers and Gerstman 2001). This is the perspective of brands, but the tech giants themselves are brands and they will need us to rely on their gear, operating systems and interfaces. AR will take off as soon as a big company like Apple or Google figures best the correct interface and use for AR. One thing is for sure, AR will demand participation and require a whole new data presentation model and responsiveness, much as it happened with Apple and the WatchOS for smartwatches. As McLuhan predicted, each new medium becomes the content for a previous medium. AR might become the new media spin-off from the smartphone era.

4. Our Day and Age

For the author Neil Postman, following McLuhan's footsteps, we are witnessing a "technopoly", which, in his regard, is a mental state, a stage of culture whenever culture is indulged by technology itself (1994). Today, the top global brands are technology brands like Apple, Google and Microsoft. Despite Intel's prototypes for smart glasses, there is the chance that GAFA group, formed by Google, Apple, Facebook and Amazon, might come out with a smart glasses' category of products. But this is a sign of something deeper happening in our culture. Technology has become omnipresent in our lifestyle, from cloud services, streaming music and movies, AR kits, social games and location-awareness-based applications. If the first machine age was based on the Industrial Revolution, the second machine age is relying heavily on "ideas, mind, bits and interactions" (Brynjolfsson and McAfee 2014). After all, we want to deal with the digital world, but we want to leave our computers behind. The logic is being followed by Apple since 2007, the time when the iPhone was released. The formula is this: Apple releases a notebook so we use the desktop computer less, then it releases the smartphone so we use the notebook less, then it releases a tablet for middle uses, then it releases a smartwatch so we would abandon almost everything else. But the legacy of the smartphone era is that the smartphone is no longer king of sales, but it still works out as the remote control for pretty much everything we do, from organizing tasks, typing, email or chat with friends. But that might be about to change. There are three ideas we have to keep in mind that pave the way for what AR might become. First, John Schwartz, Sun Microsystems CEO in 2005 speaks of "Participation Age" (in Prinz 2014). And yes, even with AR interfaces about to be shown to us, it seems that we will use it for social purposes.

Here the interface has to be really slick. Second, Ridley and Parsons claim that now we live in an "Imagination Age" (2010). And as for AR this means that it has to present to us new worlds of data, opportunities and forms of interaction that have to be highly engaging, seductive and lead us to go beyond the world of screens. Furthermore, in third place, Daniel Pink speaks of a "Conceptual Age" (2005). In his regard, the conceptual age means that we, the public of users, will be enticed by pattern recognition, empathizers, creative works and concepts and ideas that drive us into something smarter. In this part AR could prove to be useful, sexy and draw attention from the early-adopters in the demographics of the tech giants, should they release AR-driven gear. There is also the author Izsak, who unravels that "this is not an Information Age, this is an Everything Age" (2013). For him, the challenge that today's user faces in this day and age is about having or not access to everything as long as we are connected. The question is that since tech giants and the GAFA group proves to be driving change, the demographics of the future will most likely be connected to their services, apps, networks and especially through their gear. And here we close the loop. Much as the fighter-jet the pilot uses AR to look at data while flying the aircraft, the AR user of tomorrow will most likely use AR smart glasses to control the digital world while doing something else. Just as Apple behaves as though making things simple by getting rid of them, and rendering the interface cleaner and simpler, AR will do just that, it will extend and augment reality by cutting a big portion of the chords to the computer gear, which is, in our point of view, a legacy of cold war media. The future will be about control, interface and connection, data and play (Elias and Dessain 2013), not about mainframes, netbooks or desktops, headsets and cables. The future will be augmented.

5. Evolution

The issue with AR is that it was desired to be full-fledged and all at once a ready-made concept. Reality proves otherwise. It shows us that the medium of AR is turning us into voyeurs, into voyagers amidst the maelstrom of information. We have to stress that the AR medium is not a single medium, a novelty nor a trend, it is a piece in a larger puzzle. Such a larger puzzle which we entitle as "macromedium". We shall explain further, AR, like other new media, fits in the macromedium system, which is to say that the centerfold is the macromedium. Not AR in itself. By being a key feature in the new medium of media in a macro scale, AR is pointed out as the new language, the new semio-capital, a new model for communication and interfacing with information. Such an approach is most likely to be that of an Apple AR headset or AR Glass. This means that AR makes sense when there is already an ecosystem of digital media and computing devices, or a system of commerce, or a social media-enabled mecosystem. The fundamental point to understand here is that AR is a way of dealing with data while on the go. By being such a piece in the swirl of information at a macro scale, AR steps in to become a new paradigm even for establishing communication. Once there is an ecosystem, much as there is a whole architecture in the military datalinks used by jet fighter pilots to connect people, networks and avionics, the civilian form of AR is actually supposed to be an extended space. Just as GPS and the networks were once military-based systems, and now they are widespread across society, AR will be soon the next form of communication. Even some videogames and movies portray AR as futuristic. The problem is not if the extended space is to be critical, or seen in a naïve form. The question is that AR will be brand-based and it will rely on infrastructure. AR will branded and it will be fully functional as an architecture. In other words, we are not discussing AR as a single medium, because it never was that. There were always networks, jet fighter designs, manufacturer's ideas, and constant interlinking to a wider system. When we speak of the evolution of AR we are to keep in mind that the macromedium is crucial here. The system architecture, whether it be corporate, military, or commerce-based (as in the mecosystem), is what will define the success of AR and what likely will determine the fate of AR. The AR that visionaries depict implies something that is always on display, constant interlinking, with a seamless data connection, and it seems to be a highly reliable interface model backed by an investing corporation. Science fiction aside, AR will be like a club. You will have to pay to play. It will be a pay per use interface. Perhaps the first interface that user-consumers across all-over the world will not mind to pay to experience it. The trick is to connect it to a gadget, a headset, perhaps some glasses. The features, however, will only be used in their ultimate form and unleash the best experience once a user-consumer confirms to be an authorized market.

6. The Macromedium

The new fact and motto is that the internet is the stage for every kind of media consultation, sharing, uploads and downloads. The internet is a library and is a stage for acting, file systems, interfacing and a laboratory. This medium, which now is maturing, is the medium for all media; it is, actually, the first "macromedium", a medium that gathers all the applications, all kinds of media's files, platforms and services. What has been making the macromedium overwhelming as the days go by is the fact that being a medium in the present age means it is dedicated to all generations. The internet is the medium of all mediums, it is the medium devoted to all ages. One thing to be considered is that the people of different ages converge on the internet, and we are all simultaneously online even more aligned with the macromedium that it encompasses, spreads and informs.

For this reason, the Internet is macro for being gigantic and it is a medium because it follows the actual trend that everything attaches to it regardless of its format. All the contents and provisions develop themselves around a medium that unifies them all, and each user approaches it. We are also considering that the younger people from the generation Z and from the Generation Alpha (even younger) spend a lot of time online. Regarding the new generations, what one can say is that the only thing that remains is the internet, e.g., the macromedium, and this medium self-configures itself. In a very close future, we will be "human addendums" of a content, service and communication vicious machine wired forever to terminals and the thriving of this macromedium is such that words like offline do not make any sense. AR will be the interface and the way to deal with the macromedium. This way, the macromedium will have an impact way bigger than the computer. What is happening is the web 4.0 computation's experience. This is, beyond question, the age of the smart network linked with people and smart machines. For the first time in the digital history, we are forehanded by a machine of the machines which controls the digital, the space that once was the iconic space designated as "cyberspace". We gave up making choices. Moreover, this is a machine that makes those choices for us. Furthermore, what some people consider as a regression is truly a remarkable progress. We have before us a macromedium, which perceives, consults, anticipates, guides and manages the information for ourselves. All the borders are highlighted since the simplified digital understands us and arranges each user's life.

Without the differences between being online and being offline, the thing is that we are even more synchronized with the macromedium that allures us with its proposals, products and services. In the age of the unifying multimedia medium, what is happening is that we are more consigned to the condition of consumer-users. The Internet macromedium is a result of the information society plus the capital society. Hereupon, what remains is a new instance that does not have a center (if there ever had), in order to have a tendency to make us interact only with a constellation of data, considering that the bluntest phenomenon is the unimedia and we are facing an unstoppable convergence. The macromedium is a medium that allows the corporations to better-know our profile. AR is that media form that permeates all connections. One thing that changed was the software, too. There is no more ultimate software. Instead, there is always a "bug" to be solved. We are in an era of unifying and convergence, such a thing means that what is left is not the product but the experience. According to this, we feel formatted to act legally with a macromedium of the originals. The copies ended, so did the piracy. What remains is the usage's experience that we access, through terminals, to the information that is somewhere in the medium that contains-it-all and attracts everybody. It is not by any chance that what endears people is the experience, the union and the convergence. These concepts have already been worked on by the corporate culture and the capital society. For a start, the Internet 4.0, capital society inoculate the information society with its codes and, thus, thriving a model of interaction with the digital that leaves no choices to the user except to test and use it. In this macromedia age, nothing belongs to anyone. What we do have is access to a huge agglutinative medium, which contains the data of each age of the humanity. AR is the new paradigm to establish a connection to the data exchange giants. AR is more than a promise. It is the primary key to establish interlinking with new ecosystems, since now every digital media brand is becoming an ecosystem based on information architectures. For instance, Chinese smartphone manufacturer is officially an Internet services' brand. It is not regarded as a smartphone maker like Samsung or Apple. However, all of these brands will have AR devices released soon to connect user-consumers to their ecosystems. AR as a medium just makes sense once it is attached to a macromedium or an ecosystem.

The huge quantity of information available nowadays proves that the consumer-users abdicated their privacy to gain access to specific applications, products and services. The digital, or the so-called macromedium, works like a space that is transmedia, hypermedia and unifying, in which machines manage our data in order to make sure that everything works better and is linked with more machines. At the same time that even more information becomes available in the Internet, it turns into an even more privatized and functional space only if the users subscribe themselves. The free-to-use Internet ended, so did the free contents. Together we are a legion in the macromedium where the compulsory future imposed for us is to consume things. AR is the coming gatekeeper. In the future many people will be befuddled when they think that a pre-history, a remote phase which existed in the Internet, in which amateurs set the consulted data because now everything is branded. The macromedium seduces us to adhere to new mediums and proposals. AR like VR is a proposal, but AR can be used outdoors. That is a key advantage. The big difference in the present is that this network recognizes us, it knows what we do and what we are going to do. We are becoming as predictable as the 80's videogame characters. Somewhere in the macromedium there is a brand that has acceded to our data and decided that it knows how to convince us to join the novelties. We have stopped being surprised by the proposals. We do not possess antibodies; thus, we are defenseless towards the macromedium. This enormous medium contains data within data and sub-media that we even are not aware of, but they surely know who we are. In addition, what makes all this fascinating is the fact that to the younger generations the Internet is healthy, normal, functional and cool. The positive side is that in the present any person with a smartphone can do a lot of things. So AR is a likely sister tool of the macromedium. Like right now, that we are all terminal users as we use unfinished devices, the Internet connection becomes more prominent, mandatory, technical and systematically necessary. The digital equipment only makes sense when connected to the macromedium to take part into a big data constellation, which is the web 4.0, meaning to have the power of the world-culture in the grasp of the hands. Or under our gaze, should AR glasses set free from military models and spread across civilian society.

Over the last decades, the all-encompassing medium was made with few gadgets and expansions. It is, in fact, the result of many media, brands, platforms and protocols, which culminate in the smartphone like a portal to the world's culture. The access that a consumer-user got today is a simplified and privileged one. The experience that unified and formed the unimedia is due to the fact the macromedium has become more seductive and reduced. We have ascended to the Internet macromedium by using our smartphones and in there we stay, consuming, being reformatted by the codes of this medium. We are the product and the message. Everything in this internet is a fake flux because we make so many things and so many different ones that we are in a practically in frozen-mode, focusing on ourselves, as we returned the final product of the digital handing over our information to the macromedium. This massive and dynamic medium has its own structure, a super-structure. Once inside the macromedium everything is turned into a constellation, we consult strings of data from files of even more data. We are archivists and collectors. We want to be in a bigger and polymorphic network, and as we can recall it all began with smartphones and their software, the apps, and then, we became sluggish and we chose the super-apps—they are the last bricks in the data constellation of the macromedium, they are unifying software pieces (which are about to be extended by AR). Inside that, the consumer-user makes everything without leaving the app, always inside and always online. The today's individual has in the Internet a way to become proficient. Now it is impossible to be outside. It is unnatural to be outside the macromedium. For what reason should we be out? The normal attitude is being inside, wired, updated and synchronized, apparently informed. Nowadays, nobody uses the computer to be online, the smartphone is the ultimate portal and access gateway to the real through the virtual macromedium.

Nowadays, the problem of the digital lies in its dimension and it is there that all the assistance and aid mechanisms come in so that we can check what is online. There is too much available information in our present time. These territories do not have some measurable charts, because they are dynamic and volatile. Yet, they transform themselves into fake fluxes. We tend to use only one app, only one brand, only one ecosystem and by doing this we become prisoners from nexus. We are overcome by the related paradigm—we are more connected and yet, we are more disabled due to the immersion of existing information. What caught us is the information and consumerism, creativity and novelty, knowledge and culture, technology and science, but the consumption is where we all find ourselves more frequently. There were moments in which the world was bigger than the Internet, then there were a second stage of this medium, which had as many spaces as the Internet; during the third stage, a unimedia process happened, and in the actual web 4.0, we have more Internet than the world. The macromedium became "worldlier" than the world itself, and it is now a separate world, unifier and demanding of our attention. "A medium in which everything is digital and uncomplicated", that was a goal to be reached some decades ago, but it is now that we truly reached to a phase where the macromedium is only one thing that we access to. Moreover, we are eager of information and we learn online with other people from a constellation. We are always in social mode and interlinked, we are interested in many different things (and even more interested in the good sense), we are adults and curious, we are proficient citizens of this new digital republic where every vote counts, and we all have spectators. In this web 4.0 phase, the experience we have got from the digital changed our habits. We do not know how to do anything offline. To possess offline devices has become suspect for many people. According to the mainstream opinion, the normal thing is being inside the wired social information flow in the macromedium. In addition, despite everything fits inside this medium, every consumer-user has its own unique and unified experiences, and no one sees or logs into something like any other person. The data constellations are of such magnitude that every path to be followed is countless, be it in a search engine, app or in a social network. It seems like we are more interlinked to one another, but on the other hand we are more distant from each other. There is only a link inside the macromedium. Outside the macromedium, there is only loneliness, fragmentation and alienation. Inside it, everything makes sense. We cannot be off because we are governed by some sort of mandatory fate. Being linked to the Internet has turned into a necessary priority. There is a neo-bourgeois horror of emptiness. In general, all people want to have everything and to be connected with everyone. We need guidance in this "pseudo digital desert" disguised as a cosmopolitan city. It is already common to be used to the commercial noise of the network, and that we do not stand the loneliness and the emptiness, we have difficulty in being alone with ourselves.

The main question that stands up is the fact that we are incapable of returning to a world without any mediation, media and announcements, games and brands, promotions and systems, software and platforms. One of the macromedium characteristics is the way it makes us feel like citizens of the world-flux. However, instead, it is capturing our attention and holds us by showing us mostly entertaining content. This new macromedium is as a comfort space, a playful data zone of learning and consumption. And when before there were elites and masses, now we all become elites and masses, spectators and producers.

We are constantly bombarded with news about products, science spreads new feats and technology overcomes itself every two months. Everything changes, but at the very same time as we have a unified experience of the split landscape, what is happening is that it does not have the same time concept. The future is not so distant, and the past is not, too. It is a kind of an eternal present. We look back and forward always in a privileged position of a present so viciously eager about novelties. Nowadays we can find everything on Google or on YouTube. The macromedium leads us to a better way. It is impossible to surpass this system. In this moment of eternal novelty provided by the web 4.0 the social changes and no longer these come from the outside but from the inside. Moreover, as we naively agree to give away our data on behalf of the macromedium proficiency, what is up is that this medium becomes even more agile, smarter and convenient. It scores on everything; it guides and corrects us. It jeopardizes our freedom of suggestions and rules. It is no more the man leading the machine. It is the machine leading the man, the addendum of its digital terminal. In addition, like in the twentieth century that the massification conquered the society from the masses and from the mass media, in this twentieth-first century the datafication is prevailing. Our data are the fuel to the new macromedium. AR is the new extended paradigm, the rightest interface in pop culture.

There were many paradigms: one was about the screen, after that there was another one about the window, and after that the one about the portal followed by the one about the network, and now the constellation seems to be likely in a society unplugged from the reality but pretty efficient in the digital relationships. In the new space, the concept of “macro” is apparent everywhere. Every digital thing has a super-structure behind its curtains. It is so true that our relationship with the time is also a link towards the great archives of the real past. The unified experience sorts out for us the problem that all is excessive and what should get on is having a simple relationship with the digital. What we feel is due to the fact that everything seems to be always available online, either things in the present or things from the past. The eternal descendant from the digital now feeds up from the past. The more the macromedium knows about who we are and what we do, the better it anticipates our choices, and we do not need to leave the place because we are gifted with news and novelties according to our profile. We are always in line in this "always". In the new macromedium, the space we attend is a semi-public space. We either are on the streets, or in our house, or, also, in the work place. We are always wired and that, which is initially fascinating, ends up being somewhat scary, as time goes by. We are always working and always entertained. It seems like a contradiction, but it, indeed, is not. However, it is worth mention one thing: all the macromedium is a corporative space. So, if AR is a primary tool in the future of corporative spaces, it makes us think about it.

The reader may question where the revolution resides. Well, it resides in the fact of having a consciousness ourselves, that the changes from the Internet mutated the society, which means, every one of us at all time. "Time" is our interface to move forward or backwards in the macromedium. This way we won't miss anything that occurs in the reality or in the digital file, too. We can always go back whenever we want. The error was eliminated from the system. The error is now rare. For all this, the data constellations we have the opportunity to look into are simultaneously playful and corporative. This new space is out of the control with those who seek the rarest things of all, because everybody has, see and buy the same things. Due to these reasons, the "non-mainstream" people are endangered. There is a lack of total connection and original connection on us. Again, we are being massified in some sort of new eternal digital that encompasses and embraces it all. We seek to search in order to find something "truly" new that belongs to our time, since the macromedium lets us borrow things from the past and the glimpses from the future that previous generations had about the potential of our present. The macromedium for sure will be accessed by the extended space, the interface of AR much as alls are accessed on a smartphone now.

7. Conclusion

AR is an interesting concept when it comes to futuristic interfaces, but whereas its military origins have made it attached to hardware, possible mainstream interventions might likely connect it to a companion device such as a smartphone, at least for a while until AR matures and emancipates like any smart device these days. In this article we sought to understand the concept, features, communication model and what it means for interface designers, but most of written works about AR are mostly object related. It means that AR is always an application but in our point of view is something more, it is both a technological aim and the future of all interfaces as well. In the future, most concepts and theories we have presented here will resonate in every day consumer's lives. AR will succeed where VR fails. It is supposed to be our connection model to the digital media, and, in becoming so, it might be the most important media change over the last decade and a half because AR is thought and designed to be an extension, unlike VR that was an investment in "immersion", but since immersive media do not have to be about Virtual Reality it just so happens that positive implementation of AR could trigger through correct interface design more innovative forms of immersion, being AR deployed as the true interface for third generation images, perfect for the publics yet to come. One thing is sure, despite all positivity inherent to the AR concepts, the key element is that the tech giant brand that first gets it right unfolds a really new category of digital media with specific applications to marvel the audiences. And thus, we will be as connected to computing and data in an intuitive way much as the jet-fighter pilot is with the aircraft he is flying. When he flies, the AR interface becomes intuitive. The pilot just "interfaces", and that is it. He is not thinking about the system's architecture. It just works. It is like electricity. We do not think about it. We just flip the switch.

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6

Architecture, Virtual Reality, and User Experience

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1. Introduction

The possibility of visiting a place before building it, walking through it as though it is in the real world, interacting with the hands opening its doors, turning on the TV, or even stretching to get an object on the top shelf, sounds like a desirable to aid in architectural design, especially when the focus of design involves the user experience (UX). Until recently, the experimentation with architectural spaces before the actual construction was rare for either the client or professionals in this field. Hardly palpable it required the execution of at least part of the construction on the natural scale (or a big mockup), making it almost impossible to experience the place in advance. This undertook a great effort, time and significant costs (Klerk et al. 2019, Kieferle and Woessner 2019).

Visual contact and interaction with virtual environments on a 1:1 scale allows for observing and exploring an architectural project as if it were already built. In addition to this, the realization of natural human movements such as standing, walking and using ones hands to interact, results in a spatial perception currently without parallel when it comes to

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the tools commonly used by architects. Therefore, users can discover the place and get sensations similar as those when the environment was built.

In general, VR makes it possible to create an illusion in the human senses, especially in vision and hearing. Even with limitations like the absence of materiality, the application of the tool in architecture allows for filling a gap not yet filled by conventional methods. This can be demonstrated in terms of time and price. Allowing the user to explore a project in an interactive and full-scale way.

Recent technological advances and popularisation of VR in various fields of knowledge, especially in architecture, enhanced the use and dissemination of this technology in the teaching and professional performance of architects. This offered a tool that inserts the user into the project, providing the author and client experimentation of the place from the initial stages of ideation to the presentation of the finished product, approaching both the creative act and user experience.

The real scale visualization associated with the natural movements of the human body and the interactivity with the environment, contributes significantly to a fruitful application of VR in the field of construction when well explored. Therefore, the present work discusses the benefits of using immersive Virtual Environments (IVE) in the daily architectural field, focusing on the user's experience. The first part presents concepts whose knowledge is considered essential to improve the usability of VR in architecture. Subsequently, three different subareas are discussed to demonstrate some of the most frequent modes of application: (a) *architecture teaching*, (b) *creative process* and (c) *historical heritage*. The methodology used involves research in 67 scientific articles published between 2017 and 2019, as well as works before 2017 that analyze the history and concepts on the subject.

2. Methods

A literature review was performed on the Cumincad database (Cumulative Index of Computer Aided Architectural Design), which concentrates on computer-aided architecture projects published annually at the events ACADIA, ASCAAD, CAADFutures, CAADRIA, eCAADe e SiGRADi. We used the following keywords: virtual reality, learn, pedagogy and heritage, referring to the years 2017, 2018 and 2019. Also, data bands from the websites were consulted, sciencedirect.com, mitpressjournals.org/presence, and other constants in the bibliographic references of the texts read, as well as masters and doctorates associated to the subject. The works were selected according to the content, explicitly separating those related to VR, architecture and one of the three subareas (a) Learn, (b) Creative process (c) Historical heritage. The universe of 67 articles was reached. The procedures adopted are close to those used by Tiani[1] (2007) and Milovanovic et al.[2] (2017).

Once segregated, the annotations began, and furthermore the mind maps that aided the interconnection between the subjects. Finally, following a logical order, a literature review of the topics below took place.

3. VR, Concepts and a Brief History

What is VR? How can it influence architecture?
Since Ivan Sutherland published his first paper on the subject in 1965, several researchers have developed in-depth works on the concepts and technologies regarding virtual environments (Blanchard et al. 1990). At the time, Sutherland (1965) proposed "The ultimate display", describing: "[...] be a room within which the computer can control the existence of matter". Later, Ivan proposed an equipment called the Head-Mounted Three-Dimensional Display (Sutherland 1968), a technology that has evolved considerably to the present day, known only as Head Mounted Display—HMD.

The term Virtual Reality was only defined in the 1980s by Jaron Lanier (Machover and Tice 1994), who at the time needed to differentiate between traditional simulations and the virtual worlds he was investigating (Machado 1995).

VR is often described as a computer-generated environment in the contemporary context, offering the viewer a compelling illusion of being in an artificial world. It allows the observer to move and interact naturally in a way that the user can temporarily or partially abstract from the real world (Paes et al. 2017). Rebelo et al. (2012) consider the concept of VR to be centered on the feeling of being present in one place, although the person is physically in another.

3.1 Related VR Basics Concepts

Before going through the chapters that demonstrate the practical application of VR in architecture, it is essential to know some basic concepts, which are: immersion, interaction, imagination, presence, as well as others equally important, but more focused on physical equipment such as stereoscopy and motion sickness. In the description of each concept, there is a highlight of its importance in the field of architecture.

[1] This master's thesis discusses the use of the computer in the teaching of architecture. The methods include a bibliographic review of a set of articles present in the annals of the SIGRADI and PROJETAR seminars between 2000 and 2006.

[2] This paper provides research on AR and VR devices, focusing on architecture design and teaching, from a set of works selected in conferences and journals.

3.1.1 Stereoscopy

In 1838, Sir Charles Wheatstone related in his paper that when observing objects at a long distance, the optical axes of both eyes are almost parallel, therefore the image perceived in each eye was practically the same. This reading changes when the object approaches the observer, causing the intersection of the optical axes to occur. This results in the observation of a slightly different image for each eye, and the combination of both in the brain results in a notion of depth (Wheatstone 1838).

At that time, Wheatstone created an equipment to visualize this phenomenon, which worked through the use of a pair of geometric figures with slight differences of perspective (Silverman 1993). This same technique is used by today's virtual reality headsets which have two separate screens, aimed individually at each eye, providing similar two-dimensional images whose combination of both in the human mind results in depth perception.

For this reason, when using a current VR equipment, if a user observes an object coming towards him, he has a latent feeling that there will be a collision. That is, the notion of approximation is not only due to the increased size of the object on the screen, but is due to a combination of distinct but similar images in each eye and interpreted by the brain.

Bringing this into the field of architecture, it becomes relevant to understand that even when experiencing a simple building in VR, objects close to the viewer and moving toward him, like a door opening, tend to convey a high sense of depth, enhancing the idea of realism in the user's experience due to stereoscopy. Renner et al. (2013). Renner and Lin verify that stereo vision is most effective when observed objects are less than 3 m apart, a frequent occurrence on a virtual architectural tour.

Certain software allows the possibility to generate 360-degree images, offering the option of immersive observation (through an HMD). This type of experiment can provide great results for design presentations. Still, if the image is mono (single image/video) type, then the quality of the experience will be reduced as the effect of stereo perception is almost nullified. For this reason, it is recommended whenever possible, especially in project presentations, to opt for stereoscopic views.

3.1.2 Presence

Many authors consider Presence a very relevant element in Virtual Reality studies. Steuer (1993) proposes that the term Presence is the key to the definition of VR. Therefore, it is a state of consciousness, a psychological sense of being in one place even though physically the body is in another place (Slater et al. 1996). For Slater, higher levels of Presence means more chances for the user to act the same way that they would if they were in the real world.

In the architectural field, as in most areas, having high levels of presence is desirable. Therefore, the richness and graphic realism of the scenario, the fidelity to real-world proportions, and the visual effects added with good interactions, can significantly enhance the sense of presence. Also reducing external noise (sounds from outside the environment or objects that prevent free movement) contributes to a more exceptional experience.

Another factor related to architecture and the sense of presence is the participant's involvement with what he will experience. In this case, being the house in which the client will live, his imagination will undoubtedly be sharpened, and the presence will tend to be much higher than if the same person were viewing any building. In short, the person's subjective relationship with the project will reflect on the deeper levels of presence, thus enhancing the user experience.

3.1.3 Immersion

Immersion refers to the sensation of perceiving oneself inserted in a different place than ones actual physical space. It is different from the presence because it is not a psychological state, but the hardware's ability to isolate the user from the real world, allowing them to perceive themselves inserted into the virtual environment. Thus, for example, devices with broader viewing angles tend to offer more efficient immersions. Feeling immersed does not necessarily translate into high levels of presence (Slater and Wilbur 1997); still, equipment that offers a good immersion quality can increase the sense of presence in a given experience.

In architecture, high levels of presence are desirable, so equipment that offers a good immersion will significantly contribute to the quality of VR use, whether by professionals, students or customers.

3.1.4 Interaction

In VR, interactivity refers to the interference that the user can make within the virtual environment. This will result in one or more reactions of the environment. A user action—such as a simple head movement or body displacement within the virtual environment—translates into a form of interaction (Sheridan 2000).

In architecture and in many other areas, interaction is one of the main advantages of VR, especially when it comes to studying and presenting projects. Within a virtual environment, it is a feature that enables the user to use their own hands to light a lamp, open doors, exchange finishing materials, focus vision on a specific element (It can be an object, the structure of a building, plumbing, electrical, various), among many others.

Interaction requires the user to concentrate more intensely on the action taken. For example, stretching his arm to turn off a light switch. In doing so, he tends to focus on the movement of his hand until he reaches the visualized button, which makes his attention more directed to the virtual world (forgetting briefly about the real world). In consequence, the levels of presence increase and the sense of realism also tend to be more significant.

3.1.5 Imagination

In Virtual Reality, this is the variable that helps the mind ignore the imperfections of digital scenes, increasing the perception of reality in the experience. Sheridan (2000) calls this suppression of disbelief. The author explains that this is important for the user to ignore available clues that denounce a VR experience as unrealistic. That is, imagination helps keeping the mind focused on the virtual experience.

Knowledge of this variable allows us to observe that there may be good perceptions of architectural space in VR even without focusing on realistic finishing (Paes et al. 2017, Dokonal and Medeiros 2019). The work of Moloney et al. (2017), for example, proposes non-photorealistic immersive systems for the historical interpretation of architectural drawings. Therefore, too much detail in a virtual model may not be necessary for an excellent experience to occur, depending on the goals wanted. On the contrary, the effort to develop ultra-realistic models without proper care can impair display fluidity by pushing hardware processing to the limit. In this sense, fluid and interactive experience in a virtual environment can be more exciting than a highly detailed slow environment and with little or no interactivity, even with low photorealism.

3.1.6 Motion Sickness

Understanding the concept of this term is essential to take some precautions to prevent specific experiences in VR to become unpleasant, causing dizziness, nausea and other symptoms.

The 1990s saw VR's first boom in the market, but the expectation created in the media was not met, as the technology was not adequately developed for the general public (Voshart 2015). Thus, many of the people who used the equipment in the 1990's reported dizziness, nausea or some malaise. This often occurs when the images seen through the eyes (through the headset) do not match the movement of the human body, causing a conflict of information in the brain, which can cause discomfort.

In architecture, knowing this concept is especially important because some design software allows one-click access to VR. However, if (a) the model is too detailed or (b) the computer hardware is not adequate, the experience may become unpleasant, causing motion sickness. In this case, it will be necessary to review a, b or both. Also, knowing about it can help guide users who have had some bad previous VR experience by explaining the reasons and encouraging them to try again.

3.2 VR in Architectural Education

Overall, the education sector considers information technology as an essential tool for learning development (Sampaio et al. 2010, Bashabsheh et al. 2019, Sorguç et al. 2017). The presence of Virtual Reality in architecture schools is not new. For example, in the 1990s the works of Donath and Regenbrecht (1996), and Alvarado and Maver (1999) already presented relevant cases. With technological advances, VR became popular again in the 2010s, primarily by HMDs. This brought in a new batch of work with fruitful results from the application of VR in various areas, including architecture. In this part of the work, experiments are reported to demonstrate the use of VR as a tool that improves the architectural teaching process.

For example, Angulo (2015) used the immersive environment with undergraduate and graduate students to understand the proposed design problem in class. Later, they would evaluate their project solutions. The task was to design the lobby of a building, considering, among other requirements, the emotions that the guests would feel on arrival and departure. It was also necessary to analyse the space from the affective point of view. This is particularly difficult primarily because of the degree of subjectivity. However, such analysis was facilitated through the use of VR, as students were able to take advantage of the full-scale reading, stereoscopic vision and natural movements of the human body-aiding in the perception of space and sensations that people tend to experience as they enter the lobby. In this same experience, the immersion took place during the proposal preparation process (before the final presentation). With this the students got immediate feedback, which triggered improvements in the projects. The results showed that most students considered the use of virtual reality as good or very good.

This argument converges with the work of Kieferle and Woessner (2019), whose students experienced VR in the first semester of architecture school. The authors performed three experiments. In one of them, the students could use the conventional tools combined with the immersive medium. They produced their work through hand drawings and cardboard mockups, leaving the use of VR only in the final phase (there was an introduction to Revit just two weeks before submission). As a result, the authors found that many of the students, when designing were using only physical drawings and models, and were not as aware or trained about what their design would look like at full scale. Therefore, those who used VR had a better understanding of the spatial appearance of their design.

Sönmez and Sorguç (2018) verified the influence of VR in the teaching of spatial relations with the human scale. In their research, the problem proposed to the students involved the design of a kitchen for a person in a wheelchair. Thus, the students used VR by sitting in a chair and stretching their arms and hands to simulate the range of objects, thereby checking the project measurements.

The work described above is consistent with the idea that immersive tools can help bring back a better spatial and human-scale understanding (Dokonal and Medeiros 2019). For Dokonal and Medeiros, these concepts dispersed a little at the end of the last century due to the switch from analogue to digital tools but can now be rescued through virtual reality.

Teaching about "design knowledge" and space perception is among the more significant challenges in architecture courses (Sopher et al. 2017). Beyond these, other academic areas are also explored through VR to enhance conventional methods. Wendell and Altin (2017), for example, they investigated the gap in the teaching of architectural history, canonically taught through photography. They pointed out that students usually learn about a given building by looking at it only from the photographers' point of view, leaving much of the building out of student perception. This reasoning corroborates the statements of Zevi (1996), who, in the 1940s, considered that the use of photographs is not enough to represent the architecture of a building adequately.

Wendell and Altin (2017) compare an architecture history class using virtual reality to the same class without VR, limited to photographs only. Using an HMD and programming the experiments through of game production software, the authors chose the Barcelona Pavilion to conduct the research. About 50 students were led around the building and used the controls (hardware) to record their photographs, creating a unique visual record of each learner. This activity proved to be efficient in providing the modification of the students' passive posture to active involvement, where they began to act as space explorers, which translated into something particularly important in the pedagogical activity.

Also, aiming to evaluate the ability to obtain information using VR, comparing it with conventional methods, Bashabsheh et al. (2019) developed an immersive and interactive software where students learn about how the step-by-step of a building construction occurs. This included excavation, foundation, the assembly of hardware, among others, until reaching its completion. Undergraduates rarely learn this information in detail, mainly due to the costs and time required. Traditionally, the technical visits to buildings are indispensable, but they allow the observation of constructive details only at that time, often leaving a gap with other steps. The immersive tool proposed by the authors proved to be efficient in bringing students closer to the phases of the construction, often experienced step-by-step only after college.

In addition to the above, several other publications investigate the possible interference of VR in the field of architecture education, seeking to improve the user experience. The works of Milovanovic et al. (2018) and

Sopher et al. (2017), for example, discuss means and methods for assessing the effects of VR on architectural teaching. Asanowicz (2018) tried out Google Block with his students, asking them to model in the early stages. Bartosh and Anzalone (2019) described the Tilt Brush as an immersive design tool and suggested VR as a technology that can encourage students to project beyond the expected range. Other authors also share the idea that the immersive environment can serve as a stimulant in the learning process of the new generation (Sorguç et al. 2017, Bashabsheh et al. 2019).

The above research has shown examples and positive advances in methods of applying VR in the classroom. It is believed that shortly the massive use of these immersive media will occur in architecture courses, not to compete with current tools, but on the contrary, to add to them, just like the desktop computer did decades ago.

3.3 The Creative Process within VR

Perhaps the main benefits of Virtual Reality in architecture are full-scale visualization and interaction (Milovanovic et al. 2017). No other tool, digital or analogue, is presented as parallel. That said, among the range of possibilities offered by this tool, there is the realization of the creative act within VR itself. So, men begin to explore shapes on the scale of their choice, including natural. Therefore, the architect can virtually "shape" a building on a small table in front of him, and at any time, it can continue to modify the shape, change the scale and enter the building.

One of the first studies in this line was by Clark in 1976. Using an HMD 6Dof[3] and control, users manipulated the parametric shapes of objects in the EV. It was still a scenario of wire figures, but even at that time, the author already classified as exciting the sensation of manipulating models in an immersive mode (Clark 1976).

It is more common to find in the market examples of the application of VR in architecture directed towards the presentation of finished works (Schnabel et al. 2001, Klerk et al. 2019), and although there is no consensus on the most efficient method or software to develop the architectural modelling within VR (Klerk et al. 2019), existing research from the 1990s to the recently points to the positive and promising results of their experiments, for example (Jackson and Keefe 2016, Rahimian and Ibrahim 2011, De Vries and Achten 2002, Schnabel 2011, Sasaki et al. 2013, Butterworth et al. 1992, Donath et al. 1999, Donath and Regenbrecht 1996,

[3] 6DoF—Refers to a specification for VR equipment (usually HMD and controls). It means that it is possible to make six types of movement: the orientation (1. tilting up and down, 2. rotation to the left and right, 3. angulation to the left and right) and displacement in space (4. forward and backwards, 5. left and right, 6. up and down). Some devices offer only 3DoF, which means that only orientation movements are possible (Netto et al. 2002).

Hill II et al. 1999, Klerk et al. 2019). Even so, in general, the use of VR for this purpose can still be considered experimental.

Design within the VE gives architects a way of working that is distinct from those considered usual (Schnabel et al. 2001). In addition to making the creative act possible at the 1:1 scale, which is rare in conventional methods-, immersive modeling software typically requires not only hand movement (as in the case of mouse and keyboard) but also arm, head and even the whole body. That is, for an architect to model through the VE, he is likely to move as one who is "sculpting" the work (Schnabel et al. 2001). Optionally, he can choose to move up or down and observe specific angles on full-scale for modifying details. When designing using VR, it is not uncommon for a professional to decide to stand upright for more freedom of movement and to see what sensations the environments tend to elicit in users.

To exemplify the paragraph above, imagine the case of an architect designing the interior of a residential kitchen (Sönmez and Sorguç 2018). If during the decision-making process he uses VR for modelling, he is likely sometimes to stand up and extend his hands to check the range of the top shelves or open his arms to confirm that the distance between the countertops is satisfactory. Likewise—still within the VR—the designer can immediately use his hands to push or pull the volumes (cabinets, countertops, walls and others) changing the shape to the desired result, performing everything in 1:1 scale or in another of your choice.

The inclusion of VR in the creation process can allow several doubts to be verified almost immediately. In other words, after modelling the environment, the time between imagining human actions on the space and checking that this is adequate can be considerably reduced—because the designer himself will be able to move around the room and test the measures and other variables.

This reasoning corroborates with Schnabel's work (Schnabel 2011), who suggests that design through VR may require less cognitive load during the design process. Rahimian and Ibrahim (2011) also portrayed this as they investigated the impact of using the 3D VR interface on the cognitions and actions of beginner designers. Their results showed that interaction in the immersive environment improved the cognitive activities of users. In another study, when comparing the creative act between VR and desktops, VR's interactive options were faster and more intuitive (Jackson and Keefe 2016).

For the creative act using desktops, most CAD programs such as Revit, Autocad, Rhino, among others, although usually fast, require a considerable initial effort to produce architectural sketches and a steep learning curve (Klerk et al. 2019). For Rahimian and Ibrahim (2011) the use of software such as these can hinder cognitive activities during the conceptual process.

In the counterflow of these programs, others such as Trimble Sketchup and Autodesk Formit have a short learning curve and features simple modeling systems that make them best suited to the early creative stages. In this sense, Klerk proposed a software designed for immersive architectural modeling called Maketeer (VR), and compared it to Sketchup (desktop), the results showed that the usability for the early stages of ideation was better in the software of virtual reality (Klerk et al. 2019).

In addition to offering the option of interacting with elements within the virtual environment—and allowing 1:1 scale visualization—Virtual Reality can also enhance the perception of architectural space through 6Dof motion and stereoscopy. When a designer uses VR to sketch ideas, he can also use his body movements to simulate what an end-user would do in the real world. So, the user experience for a given project can still occur during the creative process, offering unmatched feedback on traditional tools, both in speed (Schultheis et al. 2012, Mapes and Moshell 1995) as for spatial understanding (Dokonal et al. 2016, Kieferle and Woessner 2019).

About the perception in the virtual environment, it is worth mentioning the work of Paes (2017) who investigated the reading of metric distances within the VR compared to a monitor screen verifying that the architectural dimensions were better perceived in immersive mode.

In the literature so far investigated, users' considerations about difficulties and suggestions for improvements to the use of VR in the context of the creative process are also present, which are essential to understand that there are positive and negative points. However, it is relevant to mention that the current state of technology development is feasible and with considerable potential to improve conventional architectural procedures, especially in the early stages of ideation. This reinforces the idea that, compared to a 2D screen, the manipulation of EVs during the design process makes professionals better understand (or visualize) the space (Jackson and Keefe 2016, Schnabel et al. 2001).

3.4 VR and Architectural Historical Heritage

Architecture is a type of art that, in general, and unlike music, paintings, and others, cannot be transported to places other than its original site, and this represents a barrier to the dissemination of buildings considered to be architectural heritage, especially those with historical value (Zevi 1996, Rebelo 1999). In this sense, VR has been widely explored to preserve and diffuse buildings and archaeological sites (Rebelo 1999).

In addition to the unavailability of displacement mentioned in the paragraph above, contemplation of architectural spaces requires more than a distance observation (as in the case of sculptures, for example)—it is necessary to enter the place and explore it walking in the most diverse directions. It is desirable that the visitors decide where they want to go and observe the place through movement (Vilas Boas 2005). Therefore, the reading of the architectural space can be considered a result of the author's intentions (often an architect, but not always) added to the effective use of the inhabitants. Or at least, added to the way visitors decided to move, look and sometimes interact.

The most appropriate reading of buildings and architectural sites indeed occurs "live." As constructions are unavailable for displacement, the virtual reality may be a way of bringing the user closer to a site visit, and providing a deep sense of being present in the building (Witmer and Singer 1998), enabling a vibrant walk, with scenography, interactions, among others.

Moreover, there are several places in the world with restricted or almost uninhabitable access, that configure architectural spaces of public interest for visitation, whether for academic and cultural reasons or even just for human curiosity. In this sense, VR technology has established new ways to explore places with such peculiarities; that is, the virtual immersion tool has helped in solving one of the most important historical heritage problems: offer access that is both secure for visitors and non-destructive to the place (Refsland et al. 2000). An example of this is the work of Mah et al. (2019), who collected 360 photographs of a Chinese temple in Singapore to create a virtual tour, presenting users with various interactive information, including intangible data, such as the religious hierarchy of deities, ritual practices, and other information.

Several reasons bring VR closer to architectural preservation, like many works since the past decades, like Stones's (1998), who found in VR a way to safeguard and disseminate with high precision the immense body of information collected about Stonehenge. This offered people the ability to virtually move between rocks and observe different textures and three-dimensional features. Kim et al. (2006) recreated a VR-optimized three-dimensional version of the Northwest Palace of King Ashurnasirpal II, Iraq (883–859 BC) for education and public demonstration purposes.

More recently, Agirachman et al. (2017) refurbished a part of a famous street in the historical and colonial center of Bandung, Indonesia. The purpose of the authors was test the visual impact of future modifications to buildings along the road, as well as help determine site-specific regulations. In the same way, Gomes et al. (2018) proposed VR as a tool to analyze changes in the historical architecture of the city of Belém, Brazil. They virtually rebuilt a part of the historic city center as it was 100 years ago, the work intended to enable the public oversight agencies to perform analyses through virtual travels in time, allowing to observe and compare how the place once was, how it is today and how it may become if a specific architectural or urban intervention is approved.

Still in the line of virtual time travel, a research group from the Federal University of Rio de Janeiro[4] developed a digital simulator to enable virtual visitation to Largo de São Francisco, in Rio de Janeiro—in the years 1870 and 2018—with the objective of reveal the city's transformations between times. The work also aims to allow the visualization of buildings designed for the city, but which were never built (Boas 2018).

Another branch of the market that has more recently associated VR and architectural heritage is the sale of immersive products in online game stores, which virtually rebuild past buildings or urban sites. Examples of this are the series that reconstruct areas of the ancient Roman Empire, allowing the public to take virtual trips in time to experience ancient Rome. Another example is the virtual architectural reconstructions of historic buildings that no longer exist, such as the Larkin Building, designed by architect Frank Lloyd Wright, built in 1904 and demolished in 1954. It is also worth mentioning the reproduction of architectural and archaeological spaces such as the tomb of the Egyptian queen Nefertari, which was scanned and optimized for free immersive virtual visitation.

3.5 Discussions

The work sought to discuss the benefits that Virtual Reality can offer to the professional and academic architectural field, especially those related to teaching, virtual modelling and historical heritage. In all three cases, positive examples were suggesting a fruitful relationship.

The researched references also mentioned some difficulties and needs for VR improvements for use in architecture. One of them is the isolation caused by the individual use of HMD, which can, for example, decrease the dialogue between students in a classroom (Kieferle and Woessner 2019). This may not be desirable when sometimes the goal is to encourage discussions between students. However, this can be minimized with the use of a TV or similar display that allows other participants to visualize, in real-time, what is being observed by the HMD user. Also, VR equipment for use in architecture requires computers with a good processing capacity, especially concerning video cards, which increases the cost of acquisition. That can make access difficult, especially for some students or recently graduated professionals.

The absence of materiality in VR is also a factor that deserves reflection. Because of this, the designer cannot perform some desirable checks on the architecture. For example, the act of pulling a chair with your hands and sitting down can be important to confirm ergonomics, but VR generally still does not offer this. It is certainly possible to plan a scene with a real chair that also exists in the virtual world, but cases like this require more

[4] LAURD - Laboratory of Urban Analysis and Digital Representation/PROURB.

time and more profound knowledge of programming, which hardly fits into the dynamics of day-to-day architectural design.

The benefits that Virtual Reality can offer to the professional and academic architectural field are unique, providing advantages that today's tools cannot achieve. VR is not expected to replace today's productive means, but rather to integrate the range of standard tools available, similar to how the computer did in architectural firms and colleges decades ago.

Finally, Virtual Reality is a technology that is still under development, which needs evolving and should evolve in the coming years. However, the results found indicate that currently, the benefits it offers outweigh the imperfections and problems described, suggesting that its implementation is viable and positive.

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7

Virtual and Augmented Reality for World Heritage Vernacular Architecture

The 3DPAST Project

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1. Introduction

World Heritage Sites listed by the World Heritage Committee are places of unique cultural and historical relevance, which demand special measures for the conservation of their integrity and authenticity. These properties also require extra efforts for their protection, which is possible through public awareness. This means dissemination of the relevancy of their Outstanding Universal Value, to all types of audiences, in order to promote their safeguard. Vernacular architecture in World Heritage properties share common values, with their outstanding vernacular landscape environment, their vernacular urban layout, their vernacular architectural features, and their vernacular building culture.

To deepen the knowledge about these sites, but also widen the range of visitors and audiences that want to know more about them, the information regarding these exceptional sites needs to be generated and presented in new ways, using more recent technologies, namely with the support of digital tools.

The digital technologies available today, like virtual reality (VR) and augmented reality (AR), if used based on scientific knowledge, present

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themselves as credible tools to promote the accessibility, expand interest and promote the conservation of cultural heritage (Paladini et al. 2019). Based on this premise this chapter is structured in two main sections. In the first section, it presents a reflection regarding the VR and AR beginning and its rise to potentially be applied in creative cultural heritage projects and then, it unfolds a systematization of digital technologies that could be specifically used for cultural heritage. Secondly, it presents the 3DPAST research project followed by its main digital outputs, using this experience to reflect on the different types of digital contents, approaches and relations between the digital technologies and the cultural heritage sites.

2. The Rise of VR and AR and its Potential for Creative Cultural Heritage Projects

Despite a rising interest and advances during the last years, VR and AR have been around for a long time. According to Harrison (2019) and The Franklin Institute (2021), the earlier attempts of creating a 3D image for the viewer, first started in 1838 with the stereoscope invented by Charles Wheatstone; followed by the kinetoscope in 1891; the link trainer flight simulator in 1929; and the View-Master, a 3D photo viewer stereoscopic that was presented in the New York World's Fair, in 1938, and was patented in 1939 (and is still being produced today). However, it was only in 1956 that Morton Heilig simulated Virtual Reality to the user, by creating the *Sensorama* experience with multisensory stimulation. During the 1960s, Heilig also created the *Telesphere Mask*, a head-mounted display (HMD) that combined a stereoscopic technology, 3D imagery, widescreen vision, and stereo sound. This was the real start and development of the VR and AR advance in technology, foreseen also by the arcade machines (or coin-op games), the video games, and the game consoles. It was during the 1970s and 1980s that simulations started to be developed by NASA, by simulating virtual space, and preparing astronauts for spacewalks.

During the end of the 20th century, VR started to be further developed in the film industry. The first feature film where virtual reality was explored in simulated worlds by characters was *The Lawnmower Man*, in 1992 (Mateer 2018). However, it was only during the 21st century that filmmakers fully embraced VR and AR, and started the filmmaking and gaming industry revolution, which fully changed the quality of storytelling. As a result, the interest in VR and AR increased exponentially, finally reaching access to the general society. This was also due to the **democratization of VR technology**, which was possible by the decrease of hardware production prices, resulting in the public's access to low-cost devices, which allowed them to be considered in daily life.

VR Festivals that used to be organized for specific expert professional groups started to be attended by the public, curious to learn more about different VR and AR experiences. This was the case of the 2018 "FUTVRE LANDS", a virtual reality festival organized by High Fidelity, a real-time social VR platform founded by the Second Life creator Philip Rosedale that had more than 500 people experiencing different interactive games, live music shows in VR, and other giveaways without leaving home (Rogers 2018); or the 2019 "New Visions of Reality: How Immersive Media change our Society?", organized by Andrzej Wajda Centre For Film Culture, Creative Europe Desk Poland, and KIPA—Polish Producers Alliance; a festival to cross and explore artistic and creative VR projects, produced thanks to creative teams with different funded sources (Creative Europe Desk Poland 2019).

Several organizations found the potential to provide **funding for VR creative projects** addressing cultural heritage and natural heritage, in order to attend the aims of their mission. This was the case, for instance of: (a) Projects that contribute to explore history through a dynamic VR technology, such as the one created by the University of Nottingham and the National Holocaust Centre and Museum: "Eye as Witness: Recording the Holocaust Exhibit", which intends for younger generations to have real historical educational experiences (The Cultural Experience 2020). (b) The American National Scientific Foundation (NSF) that funded studies to create virtual-reality simulations for industrial engineering students aiming at transforming the concept of learning in higher education through VR modules adapted to virtual settings with interactive experiences (PennState 2018). (c) Wildlife Boards and Forestry Commissions in the UK have also funded VR projects related with Nature, for instance "In the Eyes of the Animal" produced by the creative studio Marshmallow Laser Feast, an artistic journey through the food chain, where the viewer could choose to be a dragonfly, an owl, or a frog to experience life through the eyes of the animal. (d) Other creative projects also presented in festivals, were funded by administrative regions in France, such as "Gloomy eyes" by Jorge Tereso and Fernando Maldonado that explore in the VR experience, the purity of characters and of a love story telling. Authors play with negative spaces, in a dark world with lights that drive the public's attention, when following the delicate digital animation story. (e) Several projects are also funded by international foundations that are also starting to explore architecture digital spaces. This was the case of "The Last Goodbye" created by Gabo Arora and Ari Palitz, a tour guide of a concentration camp through the eyes and voice of a holocaust survivor: Pinchas Gutter. The experience was quite stunning as Gutter's pain could still be felt through the VR experience (Creative Europe Desk Poland 2019). All these projects highlight the potential for VR and AR, and their contribution for understanding history, the future of education, to be sensitive towards nature, to explore storytelling, and to share empathy with survivors. This potential for change through VR and AR could be found across all society.

Nowadays, it is common to find **intensive VR and AR courses online**. The main aim is to update professionals, and to develop competences regarding digital analytical capacity and creativity. Webinars and Courses on AR regarding architecture are also on the rise. Research labs and research centers saw the potential there is in the area and are trying to tackle, improve and transform the way to see, to understand and to address digital architecture. Several creative schools and art degrees are actively developing content creation in VR and teaching students how to capture images or create 360-degree movies in degrees connecting art and VR technology. Practical schools of gamming are also contributing to the advance of computer graphics and software development, and film making centers are cooperating with local universities and helping the advance of cinematic production (Bezegová et al. 2017). VR is not only being actively developed in University Education, but also in research and development (R&D), across North America and Europe, and more recently is expanding also, in the Middle East and East Asia. Even Africa and Latin America are emergent regions where content creativity in medium and low-cost productions are on the rise.

The European Union, throughout its Creative Europe Programme, anticipated the potential of VR technology and fully embraced the funding of creative quality projects that were opened to include virtual and immersive augmented reality experiences, reaching non-expert audiences. The 3DPAST project (2016–2020), which will be addressed later in the chapter, was one of these creative cultural heritage projects.

3. Digital Technologies for Cultural Heritage

Digital technologies have expanded the means of storing, representing and transmitting across different areas, the potential and the value of cultural heritage. Nowadays, large amounts of cultural content and data is available online. As mentioned by Windhager et al. (2019), there are namely 5 main types of digital items: image, audio, video, text and 3D objects. Also, since accessibility plays an important role in the conservation and in the dissemination of cultural heritage, the use of digital technologies could play an increasing role in the promotion and in the access of the sites to visitors (Paladini et al. 2019).

Besides encouraging accessibility, using regular digital tools could facilitate the site's interpretation, regarding the possibility of creating cultural and chronologic windows without intrusive elements. This information's overlap could extend visitors perception, could diversify interests, and create a more immersive experience with the architectural elements, namely the ones you cannot access entirely by material restriction or through its condition. This had been already underlined in The London Charter for the Use of 3-Dimensional Visualization, when advising to assure the "*use of 3d visualization methods in relation to intellectual integrity, reliability, transparency, documentation, standards, sustainability and access*" (The London Charter 2009).

The first challenge faced by research content authors is on how to format and to organize the data, regarding the wide range of possibilities related to the available digital tools and systems. Before diving into the digital wonder world, one should step back to establish a theoretical framework, focusing on the character of the work and on its results. In abstract terms, the digital approach towards the addressed object could be systematized in about seven fundamentals of interactive operations:

A. The *Digital Archive* Operation

This constitutes a virtual record for itself. It is a documentation tool that provides the registration of all related data, regarding the object of study, mainly created through digital scans. In the case of built environments, it is often related with a geometrical entity and its geographical referenced coordinates. This was presented, for instance, in platforms such as Open Heritage 3D, Sketchfab, Google Arts & Culture, or CyArk, although with different scientific rigor (Statham 2019).

The major advantage of this digital operation is the assessment of the resulting database, which could easily provide and generate interpretation filters, dynamic relations, and parametric analysis of all the uploaded characteristics inputted to the geometric element. In the case of the 3D representation, it is also possible to allocate visualization sequences of the object, to establish circulation itineraries thorough it, resorting in conditioned or free movement of the camera(s), as is the example of the Google Arts & Culture Experiment regarding the Temple of Bagan. This is used to simulate the sensorial human scaled experience throughout the building. In more simple ways, a cultural heritage site could also be archived, through photos or videos, which contributes to other richer experiences (Kwiatek and Woolner 2009). The use of panoramic photos also promotes broader access to these contents, as used by cultural institutions and tourist offices. This is the case of the UNESCO panoramas of the State of Nord Rhein West Falen, in Germany, or the 360 Degree Panorama Virtual Tool.

B. The *Contextualizing* Operation

The *Contextualizing* regards the complement of an isolated object, or a group of objects, with a virtual surrounding scenario. This helps to understand the relation and the implication of the element and, of course, of its extended impact in the territory and in the communities. The scenario could recreate the place where the element was extracted, which is common, for example, in museums that preserve and expose small and medium scale elements. In other cases, it could also simulate the supposed original background, emerging the object in a specific chronology, thus creating an atmospheric framework for the object. This is the case of the Archaeological Museum in the Czech Republic.

C. The *Reconstructing* Operation

The *reconstructing* operation conforms on one of the most used procedures regarding digital tools on built environments, namely regarding monuments and historic sites. This item aims to reconstitute the state, of a specific element, in a specific chronologic moment. It intends to provide to the observer, the simulation of the former shape of an object that has been partially destroyed or altered during time. It is usually based on historical records and tries to replicate the object in its original state or in a more emblematic historical moment. This also allows tracking the object evolution and major formal stages.

D. The *Transforming* Operation

The *transforming* operation simulates changes in a specific geometric element. This could help to erase visual obstacles, to generate dynamic archaeological windows, or to perform geometric sections and subtractions to allow a better interpretation or a more detailed observation of a particular aspect of the object of study. It could also allow adding non-existing geometric entities or to erase the existing ones, in a more playful uncompromised approach that is often detached from the usual scientific objectives.

E. The *Dismantling* Operation

In the *dismantling* operation, one tends to relate it with the geometrical decomposition of the object of study. This interaction is rather used on the structural perception of the object, rather than its sensorial simulation, being commonly applied as a diagrammatic interpretation of the object. It allows the object to be isolated, and for its components to be understood, as well as the fragments of a composed object or/and of its connections. This didactic feature is highly applied on scientific interpretations, where a deeper understanding of the isolated properties and of their performance are requested.

F. The *Complementing* Operation

This operation allows the authors to add different format data, to key contents. The methods relay in the superimposing of layers that could be independently activated, allowing the user to manage the output. The informative layers aim to extend the associated knowledge, resorting in multi-format elements, without saturating the key-element perception.

The multi-format elements are usually arranged by specific thematic areas, depending on the key-element nature and on its available records. This approach also allows it to create a storytelling around the digital element so that its cultural significance could be shared in an interesting way.

G. The *Diversify* Operation

The *diversify* approach regards the digital capacity of linking key-elements to issues that are out of its main area of study. In this interaction procedure the main goal is to establish certain relations with external aspects and different realities that could enrich the user experience. This could also be considered as a method of information, extrapolated by a problematic analogy. This last category explores the wider impact of the object of study, as it is less related with content display and more with redirecting of focus. Therefore, one could infer that while the former interactions addressed a structured list of produced contents, this last one is mostly related to creating the conditions for the user to navigate on a parallel network of information, according to his circumstantial interest.

It is evident that most of the stated categories could be implemented in a crossed or mixed system, allowing a rather huge range of possibilities of virtually interaction with the object of studied, in our specific case, the built environment conformed by an architectural or an urban specific element.

Although AR could play a key-role, most of the cultural heritage projects address first VR, as they infer the observer immersion on a determined virtual frame or a set of frames, adjusted to the existing built element considering its current state and condition.

Therefore, in these kinds of projects the involved researchers and technicians should determine and develop the support frames, constituted by the collected and selected data that should generate or be associated to 3D modelling, and rendered information.

Once familiar with the nature of the 3D visualization basic interaction possibilities, it is also extremely important to recognize the type of dynamic graphic outcomes that are produced using computer generated imagery. Once again, regarding the nature of cultural heritage and its architectural and urban focus, the present reflection is based upon the usual visual products and the most common visualization tools. The London Charter highlighted the same when referring to *"A variety of available 3d visualization methods should be carefully evaluated to identify which is the most likely to address each given aim. Consideration should be given as to whether the outcomes should be photo-realistic or schematic; high or low in detail; representations of hypotheses or only of the available evidence; static or interactive; "impressionistic" or "accurate""* (The London Charter 2009).

4. Project 3DPAST Framework, Main Idea, and Working Plan

The European Project 3DPAST grant application was submitted in 2015, under the framework of the Creative Europe Programme. In 2016, the project was selected for funding by the European Union, in a high-ranking competition among applications originated from 28 countries. As Project Leader, Escola Superior Gallaecia (Portugal) coordinated the European project, with the partnership of the University of Florence (Italy), and the Polytechnic University of Valencia (Spain). The project also received the support of ICOMOS—International Council of Monuments and Sites, three International Scientific Committees, as ICOMOS-CIAV on Vernacular Built Heritage, ICOMOS-ISCEAH on Earthen Architectural Heritage, ICOMOS-CIPA on Documentation for Cultural Heritage, and the UNESCO Chair on "Earthen Architecture, Building Cultures and Sustainable Development".

The **main idea** for the project was to enhance the exceptional significance and quality of vernacular architecture in Europe, listed as World Heritage. The project aimed to discover the 'spirit of place' of these exceptional sites, to reveal the outstanding character of their architectural heritage and to contribute to their protection. This was possible by seizing through 3D visualizations their architectural space, by studying their history and valuing what makes them special, by enhancing strategies for their tangible conservation, by developing creative possibilities with high potential, which could help bring new realities to non-traveler audiences that do not have the chance to experience *in situ* this unique heritage. The project was meant to captivate and engage **new audiences** to better get to know European cultural heritage, people that could not travel as easily, such as children, young adults, older persons, people with physical and mental challenges, financial deprived citizens, and so on.

In 3DPAST project, historical attributes of these vernacular sites were enhanced and recreated through 3D visualization and augmented and virtual reality, presented using a mobile app and a digital platform, which opened the mind of citizens to other ways of inhabiting. This was possible to develop, as the project was structured in **three dimensions articulated with three components** of work (Correia et al. 2020). The three dimensions, which were the Architectural Heritage (D1), the Historical Building (D2), and the Intangible Heritage (D3), represent a connected corpus of data that was identified, surveyed, and collected in the 8 case studies selected across Europe. The three components, such as the Digital (C1), the Creative (C2), and the Communication component (C3), contributed to enhance the collected data and the significance of the properties outstanding quality. The idea was also to structure the project in five phases: (Ph.1) Planning of activities; (Ph.2) Data collection addressed across the 8 case studies;

(Ph.3) Content Development; (Ph.4) Implementation of communication tools; and (Ph.5) Outputs and dissemination (Correia et al. 2020).

The work was developed in eight World Heritage properties. **Criteria of site selection** was based in geography (as there were sites from East, Center, North, South, and West of the European territory), in selecting vernacular built heritage in its different forms and typologies (in cultural landscape, historical centers, settlements, etc.), in having one case study per country, and assuring there was an inclusive approach with six properties from the European Union and two others from the Council of Europe geographical area.

The **selected sites** were in the west, Pico Landscape in Azores (Portugal); in the southwest, the historical walled town of Cuenca (Spain); in the north of Europe, Old Rauma (Finland); in the center, the fortified churches of Transylvania (Romania); in the south, the historical center of Pienza (Italy); and the historical centers of Berat and Gjirokastra (Albania); in the southeast, the historical center of Chorá in the island of Pátmos (Greece); and in the east of Europe, the settlement of Chazhashi in Upper Svaneti (Georgia). The dwellings that were chosen in the case studies were deeply studied through architectural surveys (intended to respond to Dimension 1), and through historical dwellings analysis (to answer to Dimension 2). Craftsmen that were still active were also contacted to share their knowledge regarding building's maintenance (to address Dimension 3) (Correia et al. 2020).

The project had numerous **outputs** which were developed during the four-year project timeframe. Several interdependent activities contributed for the development of the outputs, such as: the International Conference "Heritage 2020"; scientific digitalization workshops developed by professors and university students (e.g., in Portugal, Spain, Italy, Albania); technical workshops for the transfer of local knowledge (e.g., in Vila Nova de Cerveira); several survey missions addressed by the three university institutions to the 8 selected World Heritage case studies; several international seminars developed during the time frame of the project (e.g., "World Heritage, Vernacular Heritage & Earthen Heritage" on the 8th of November 2019; "3DPAST Conference on Albanian World Heritage" on the 14th of June 2018); the creation of several 3DPAST publications, such as "From Vernacular to World Heritage", the booklet in 5 different languages "Guidelines and Strategies for maintenance of vernacular architecture in World Heritage sites", the international heritage 2020 proceedings); interactive communication tools as the website, a digital platform to support virtual reality, videos, a digital booklet, a digital book, and an App.

5. Work Methods

The method of work developed in 3DPAST project began by the collection of data gathered from national and international archives, and through the Internet. Following, the literature review was addressed, to identify relevant issues to consider for the content's development. Site missions were undertaken to the selected vernacular architecture World Heritage properties, by researchers and university students from the three university institutions, to work on surveying, recording, drawing, in order to properly document the sites. In each site mission, observation, analyses, interpretation, and co-relation were a key-approach to the content's development in the planned publications, the platform, and the app.

The elaboration of two major digital communication tools—a multimedia digital platform and a mobile device app, with specific VR and AR interactions directly related with the built heritage—were the critical report base of an operative example, focusing both on the process of content development and content display. Besides the shared connection between them, the digital platform and the mobile app were also linked to the 3DPAST "From vernacular to World Heritage" publication, creating more interactive contents and expanding the heritage experience throughout more dynamic interpretations.

Usually associated with academic conventional data, such as analogic and non-editable information, the main intention was to promote the built heritage documentation update, trying to expand audiences and to developed innovative ways to share the associated knowledge, and contributing for the recognition and preservation of unique types of heritage assets. Complementing the approach to the mentioned tools, the text entailed the expected inputs of the designated interactions, therefore justifying, in a practical perspective, the selection of contents, processes and technological resources.

Based on preliminary survey missions, each research team confirmed the characterizing process of the heritage assets of each case study. The first developed contents resulted from the compilation of historic cartography, descriptive reports, written and filmed interviews, photographic reports for the different thematic components of the project, and the graphical representation of the built environment. The documented elements reflected the most representative aspects of the UNESCO meaningful criteria for each specific classification, thus contributing to report the uniqueness of each chosen site.

The selection of the applied methods was also related to the need for analysis and characterization of the specific study object and of the application of digital communication tools. These tools were related to the promotion of cultural heritage, to develop content to be accessed through AR and VR.

Although most of the contents for the VR and AR outcomes were centered in the Architectural dimension and their visual contents, according to the project's main aims, all the information was complemented with historical, social and, evidently, technological frameworks. The partner's core research areas, namely the urban and vernacular architecture domain, also influenced this approach. Given this fact, it was decided to assume that the architectural research and documentation were the triggers regarding the information container and the multi-experience action. Therefore, the field survey was carried out, through site sketch, technical drawing, and photography, complemented with drone survey, in the areas considered most representative of the settlements with the highest traditional integrity. The selection criteria resulted from cross-referencing key-informants that were previously identified, with cooperation from the heritage's responsible national heritage institutions and the assessment of the state of conservation of the circumscribed buildings and their role within the respective site.

Regarding the type of digital experience, there was no predetermined restriction, although the contents diversity and the different documentation skills and resources of the involved researchers, especially the outsourcing of the most complex informatics programming, dictated the concentration of experiences in: the consolidation of the *digital archive* operation, with active and instantaneous object manipulation, mostly resorting to 3D interactive models; the display of the *dismantling* operation, extremely useful in the chapter of the building technology interpretation, ranging from technical 2D layer overlap to axonometric animations; and the *complementing* interaction operation was the most common approach to relate multi-format contents, within the same thematic, and to create a more intense immersive experience, more appealing to a wider audience.

Nevertheless, as it could be conformed in the text that follows, there was also an attempt to apply the remaining basic interactions types in punctual cases, taking advantage of the existence of exceptional elements or a privilege access to broader human and technical resources, as digital modulation generated by aerophotogrametric surveys or the development of a serious gaming.

6. The 3DPAST Platform

The 3DPAST digital platform (http://esg.pt/3dpast/platform), observed in Figure 1, was one of the main outputs of 3DPAST European Research Project. It works simultaneously as an archive of the collected and produced contents, but also as an accessible and intuitive digital database, promoting multisensory experiences related to the selected World Heritage sites.

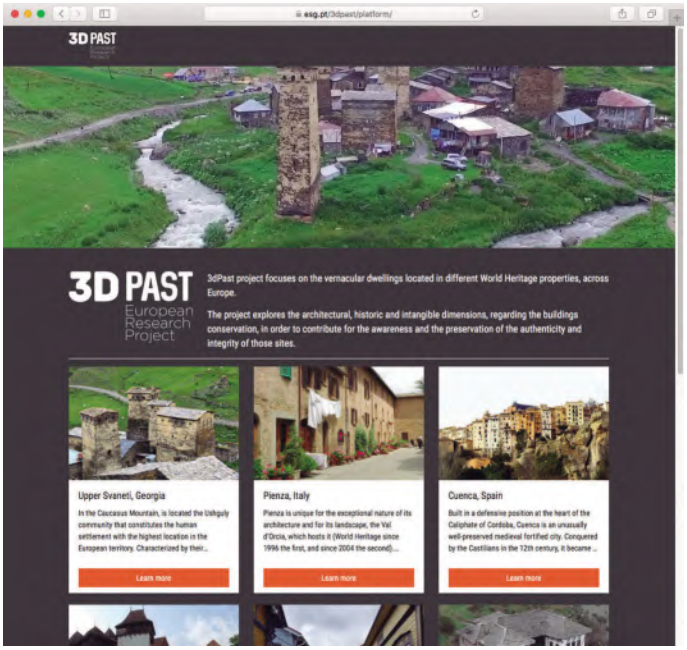

Figure 1. 3DPAST platform homepage.

The main objective of the platform was to endorse, what was conventionally exposed into technical and separated formats, into a cross-relation material exposure, enabling a broader and deeper spectrum of interpretation. The platform is directly related to one of the European Funding Program's priorities: The expansion and diversification of audiences, namely the ones related to creative industries, setting a target in public way beyond the usual academic professionals and high-standard cultural tourists that explore the related sources.

The platform, following the project's structure was organized according to the 8 selected case studies. Each case study material was presented in a progression of scale and abstraction, from the landscape characterization to the building system description, from the historical evolution to the local building culture:

1. Landscape and Settlement Category

The first section addressed the landscape and the settlement characterization. In this section, the contents regarding the territorial scale, from the geographical contextualization to the settlements urban structure analysis were approached. An interesting feature of the platform was, in some cases, the background image of the World Heritage case study, which consisted in a dynamic map, allowing the geo-reference of

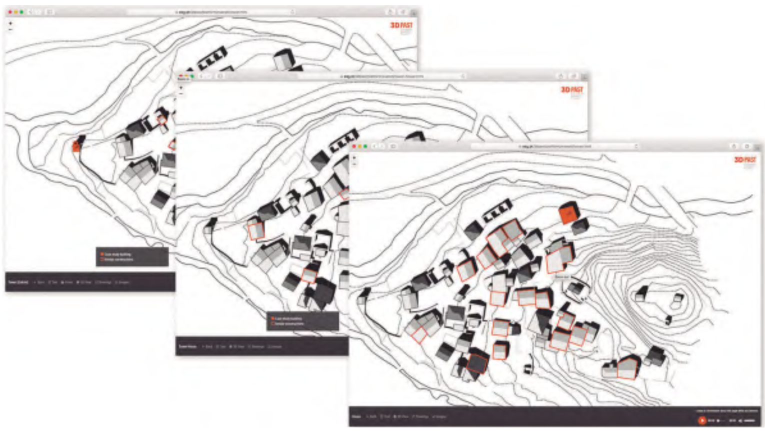

Figure 2. 3DPAST platform—example of the Ushguli Community, in Georgia, we can access three types of different buildings.

the main architectural typologies, the location of the onsite interactions or the surveyed areas, used to develop the technical characterization.

2. Architectural Typologies

The following items related with the main architectural typologies that were identified in each case study. These represented the main structural variation of contents regarding the different World Heritage sites, with special attention to the surveyed cases.

3. Building Culture Category

The following characterization category was related to the building culture, comprising technical and intangible heritage attributes, framed within the stated typologies of the previous sections. It referred to the traditional building's applied technology, focusing on the site's building systems, techniques, and processes. Resorting mostly to visual contents, this section exposed specific architectural elements and construction details. Most of the images were represented by exploded axonometric drawings, through motionless or through animated versions, overlapping different construction layers for better understanding of the construction systems. The section also comprised sociocultural aspects of the community, with information related to the main local traditional activities and their distinctive characteristics. The collected information also concerned the World Heritage site's ethnographic aspects, both actual and historical contents.

4. State of Conservation Category

As a conclusion category, the platform presented a state of conservation category, with a critical interpretation section regarding the actual situation of the sites, as well as the identification of the conservation entities and instruments.

Another important feature was the possibility for the user to access the content, through the type of content format, orienting the navigation according to the user's interest and level of expertise in built heritage technical issues.

All the mentioned case study sections comprised, at least, five different types of data that where systematized according to their format:

A. Text Format, with Audio Narration Possibility

This format referred to the original text, developed by the research team, which synthetized the collected data, regarding the site's item characterization. The mentioned texts were articulated with several projects' publications, from specialized journals to broad audience books. The texts have the possibility of an audio version, which could be activated at the right side of the screen and could be heard during the rest of the content's visualization.

B. Documentation Videos

The produced videos could integrate several types of short films, from panoramic views to aerial surveys and three-dimensional simulations of each site-built environment.

C. 3D Digital Models, with Interaction Possibilities

This section comprised three-dimensional simulations of the surveyed elements, chosen by their intrinsic representativeness. Their elaboration resorted to two main approaches providing a balance between technical resources, display objectives and geometric accuracy:

a) In a more conventional method, the researchers used ACAD design programs to create vectorial solids, representing external and internal built volumes, latter complemented by external program rendering, using material surface samples to suggest a more general materiality.
b) Stimulated by the great advances on the photogrammetric documentation area, the research team used models generated by photogrammetric systems, converting a set of aerophotogrametric surveys taken by drones, into complex digital surfaces. In this case, besides the building's accurate geometry, there was the advantage of documenting the external material textures with great detail and expression.

The character of the different methods provided significant approaches regarding the use of RV and AR, which will be depicted further ahead in the chapter.

Figure 3. 3DPAST platform—Pienza 3D model developed by UNIFI in VR view (left), First Person view (center) and Orbit view (right).

Figure 4. 3DPAST platform—three-dimensional digital model of the Zekate House after the research team aerophotogrametric drone survey.

The developed 3D objects were uploaded in the *Sketchfab* platform to allow a wide and open public access to the 3D visualization, either through goggle vision, orbit vision or through a single person view. Therefore, using a multiplatform network that could expand the access to the project's material, in this case focused on audiences interested in digital modelling.

D. Technical Architectural Plans, Composition Diagrams and Figurative Drawings

This format comprised plans, elevations, and sections of each site's specific scale. When all the data is available, drawings from different time periods can be compared, understanding better the site's morphologic evolution.

Here one could find more detailed information, especially regarding the interior of the building, exploring its partitions, its functions, and its main architectural elements. Regarding the architectural typologies, for didactic purposes, the research team decided for a more essential

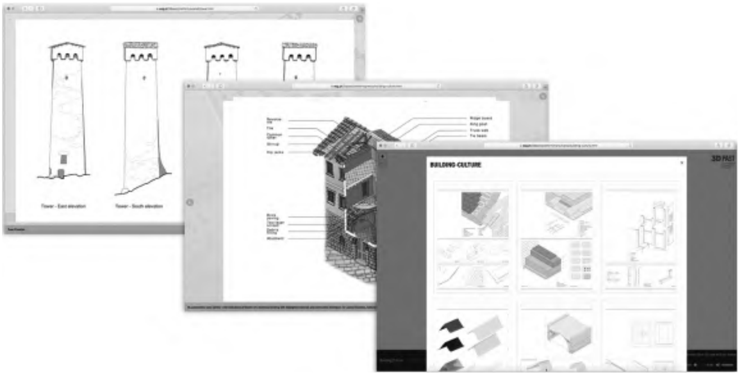

Figure 5. 3DPAST platform—examples of drawings (Svaneti, Pienza and Transylvania).

representation, to focus on the main morphological features, being able to extrapolate them to similar buildings.

E. Image Gallery

The last information format category is a selection of images dispose as a digital picture gallery. They were divided in a set of contemporary images, selected from the research team's report missions, but pictures could also be found, regarding historic graphic documents, such as paintings or old images of historical interest. In this case, the users could enable the overlap of the same view in different time periods, allowing the interpretation of the site's evolution from the past to the present day.

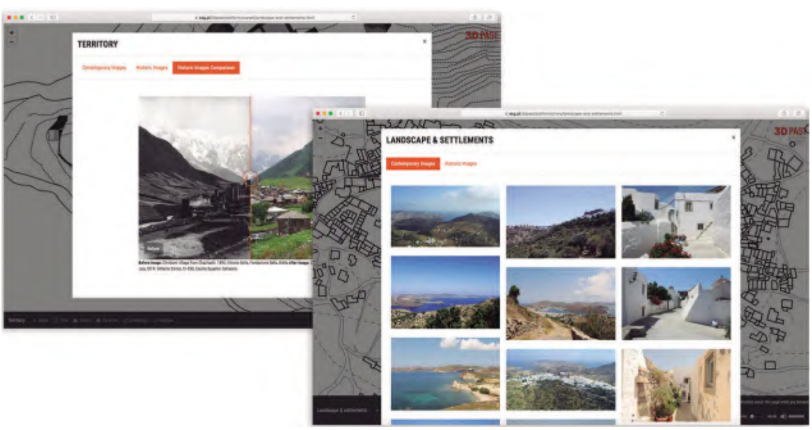

Figure 6. 3DPAST platform—Svaneti Photo comparison between XIX century and 2019; and Chorá photo gallery.

7. 3DPAST App

Another major outcome of 3DPAST was the development of an app for IOS and Android devices, also named 3DPAST, with content extracted from the project activities and with a similar structure to the one of the project's platform, presenting the same 4 typologies, in each case study. However, the content was focused on small articles with text and images from specific interest point of the World Heritage sites, and with some of them enriched with AR experiences. This app was based on the VisitAR platform and was structured as displayed in Figure 7.

Starting with a welcome screen and highlights, followed by framework information regarding the project focus and objectives and the World Heritage site location. Most of the contents were placed in the two areas of the World Heritage Site section: Sites and Book. The "About" section displayed the 3DPAST app technical details and information and links to the project partners and platform.

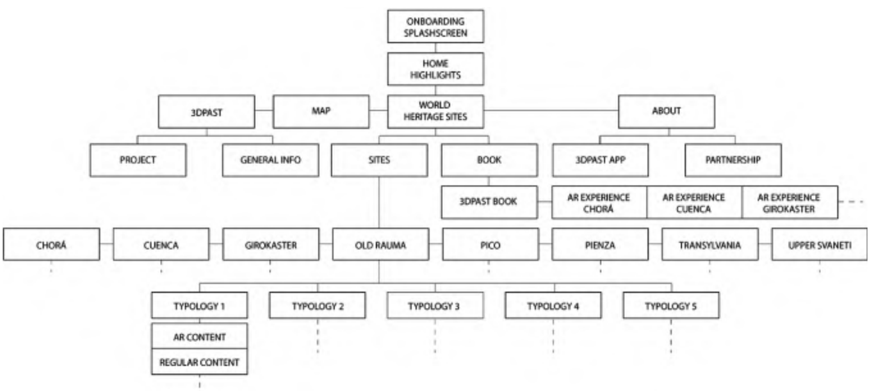

Figure 7. 3DPAST app architecture.

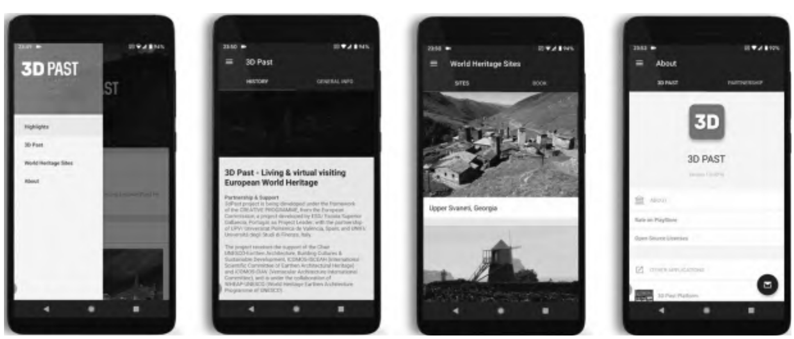

Figure 8. 3DPAST app main sections.

7.1 Content for On-Site Visit

The part containing the information for the *in loco* visit, presented most of the content. The main goal was to enrich the visit and broaden the type of audience with support of credible information. In each World Heritage section, several site-specific content folders were created, covering the typologies of content described before, from territory scale, building types, building culture and state of conservation. Inside the folders more than 150 small articles presented the specificities of the eight World Heritage sites (see Figure 9). Most of the articles presented some text with a photography, drawing or diagram.

For a selected number of articles an AR experience was developed, geo-referenced to the main map in the app, and using a mask from a building in a specific viewpoint. This enabled the visitor to trigger a richer content that presented in-depth information regarding remarkable buildings or villages. Several types of contents were developed for these experiences. One enabled the visitor to compare the present state of conservation of Chazhashi village with an older photography, creating a time-lapse of 130 years through superimposing the old content on the visitor camera/screen (see Figure 10).

Another type of AR content presents axonometric 3D models with all its main constructive elements exploded as displayed in Figure 11. The separation and identification of each constructive element allows the visitor to understand how the building was constructed. The number on the image gives access to detailed information regarding the constructive element, via audio and text. This could be complemented with more in-depth information, in the regular content article of each typology.

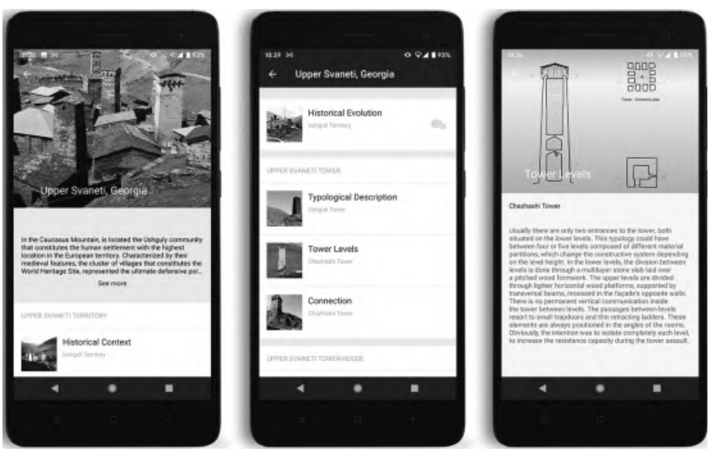

Figure 9. Upper Svaneti section with folders (left and center) and article example (right).

Figure 10. Upper Svaneti—image with historical evolution.

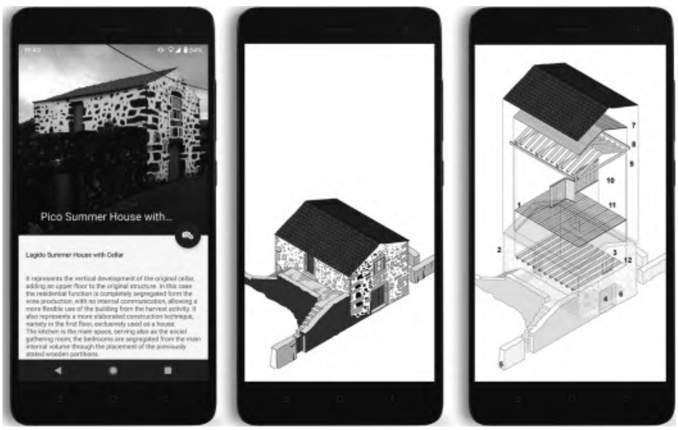

Figure 11. Pico summer house—exploded axonometry.

Other experiences entailed the use of aerophotogrametric models with audio-extra information, in buildings where, due to its nature and site location, the visitor cannot view the entire construction. Also, aerial and walk-through videos were considered, to create a holistic site view for the visitor.

7.2 Content for an Enriched Book Reading

As a complement to the main contents that were prepared for the in-situ World Heritage visits, the project team also prepared 8 AR experiences, one per site, for them to be triggered from the 3DPAST book "*From Vernacular to World Heritage*" (Dipasquale et al. 2020). The main objective was to enrich the visualization of the scientific content presented in the main publication of the project, and through that to widen the interested public. To reach this goal several typologies of content were selected. The main was the use of 3D models that were triggered from the image printed in the book. Two kinds of models were used in the context:

a) Aerophotogrametric models generated *in loco* with the use of drones that serve as *digital archive of the site*, and later developed in Metashape software as was the case of the entire village of Chazhashi, in Upper Svaneti, Georgia (see Figure 12) or the Zekate house in Gjirokastra, Albania;
b) CAD 3D Models created from the surveys, as was the case of the Traditional House in Viscry, Transylvania and Cuenca Skyscrapers, Spain (see Figure 13).

Both typologies enabled one to understand the full scope of the building or of the place, in an interactive three-dimensional way, grown out of the printed material in the book.

Figure 12. Book, app, and 3D aerophotogrametric model of Chazhashi Village.

Figure 13. Book, app, and 3D model of Cuenca Skycrapers.

Figure 14. Book, app and 360º courtyard view, Pico.

Besides this type of content, the research team also generated 360º photo views of a site that could be viewed as a panoramic photo or through VR goggles. Also, videos were created, both aerial and on the ground level, crossing the overall landscape of the WHS. These contents that revealed real moving images of the World Heritage properties, help created a real connection with the places, bridging the distance between the, sometimes cold, scientific knowledge of a book and the pleasant tourist visit.

8. Conclusion

Dealing with a complex phenomenon such as World Heritage properties, in which their Outstanding Universal Value is the fundamental aspect of interpretation and transmission, the systematization of unique and specific features of contents and sources regarding multiple sites was the first challenge to overcome on the stated process (Duarte Carlos et al. 2020a).

The identity of each place, and their components, determines a site-specific approach in identifying and developing their most relevant information. In fact, this was an aprioristic condition of the project, assumed by all the partner institutions and involved researchers. The expected digital tools were prepared to be structured under the same display organization, which followed the planned approach of the Project. The objective was to unravel the data according to a scale progression, from the general aspects to the detailed information. As the main object of study was the built vernacular environment, the data was developed under four categories of characterization scales: landscape and territory; Settlement and urban dynamics; architectural elements and building technology (Duarte Carlos et al. 2020b). If, in abstract terms, the interpretation of the pursuit elements could be integrated in the stated categories, their diversity of configuration, extension, dimension and character, reinforced the hypothesis of considering the digital experiences according to the attributes of each case study, following the pertinence and nature of the developed content's evaluation, and, therefore, assuming different systems and layouts for the VR and AR interactions for each of the eight selected World Heritage properties. Obviously, this meant to allocate eight times the number of resources in the development of the last stage of the process, the content display.

Although assumed from the preliminary stage, the articulation between different research units (composed by 3 institutions from different nationalities, with several research departments engaged) determined the variation of the documentation tools, methods, and skills. This situation revealed to be a significant challenge, especially regarding the use of different non-compatible digital programs that constantly delayed the process of access and of sharing the editable digital files of the generated contents. However, what turned to be originally a restriction in the systematization of contents and of the displayed tool structure, determining some limitation regarding the interaction possibilities development for all the selected case studies, become also part of the European diversity and richness of team work that complement the uniqueness of each site, contributing for different applications regarding the *Contextualizing* and *Reconstructing* VR and AR experiences, which have an enormous potential in the built heritage domain and their conservation future processes, since these are the typologies that could capture more attention of non-specialized audiences, and, therefore, broadening the real impact of the use of VR and AR in cultural heritage.

The 3DPAST experience, thorough its process and results, confirmed this potential. The accumulated information and knowledge generated a set of future research possibilities, extrapolating the project's specific problematic and its formal timeline. Besides the researcher's team skills upgrade in advance documentation software, the receptiveness of the local communities to these new ways of contents display created a positive approach, especially in the direct collaboration with local administration institutions and within the engagement of the inhabitants to promote and implement preservation and conservation actions.

The consideration of VR and AR, together with the exponential access and expertise on digital equipment and software, as a key tool on the architectural data processing regarding built heritage, is becoming an unavoidable resource, simultaneously as instrument and as indicator.

Presently, embracing the evolution of these perspectives in a national and international context, progresses in the quest of operative and higher impact research results for a more strategic approach to the protection of cultural heritage.

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8

Virtual Reality as a Student's Learning and Self-Assessment Tool in Building Construction Education

A Proposed Process

Khaled Galal Ahmed, Mona Megahed, Fatema Al-Zaabi, Aysha Al-Sheebani* and *Maitha Al-Nuaimi*

1. Introduction

Virtual Reality (VR) could be principally defined as an environment that is immersive, interactive and allowing multi-sensory feedback. Such an immersive environment gives the user a sense of the full presence in a virtual world, while the interaction happens through the user's body movements that mutually results in responses in the simulated environment. VR as a technology utilizes sensory input derived from the simulated environment (Abdelhameed 2013).

VR techniques have been recently applied in the fields of architectural design, urban studies and the construction industry. These evolving techniques started with desktop-based VR and Augmented Reality (AR), until recently reaching the Building Information Modelling (BIM)-enabled VR/AR techniques that this research has examined. Wang et al. (2018) subsumed VR techniques into four categories based on their relationship to 'reality' vs 'virtuality', starting from 'pure real presence', then 'augmented virtuality', followed by 'augmented reality', and ending up with 'pure virtual presence' or VR, which is based on computer simulations of

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the real world by construction a virtual 3D environment. The users can virtually jump in this VR environment where they can navigate around in real-time and real scale immersive virtual spaces. This capability has significantly helped in preparing workforce in various industries and it is therefore considered a favorite and futuristic tool in several fields of education (Zhang 2013).

Initiating a virtual environment requires both VR hardware and software installed on proper desktops or laptops that can handle the heavy task of the VR scene rendering. Usually, the VR systems consists of a stereoscopic Head Mounted Display (HMD) with a wide 110-degree field of view (FOV) that allows stereovision and a depth perception in a spatio-visual representation of the digital design of the viewed object. Unlike the traditional surface based stereoscopic techniques, the VR HMD enables individual rendering of the user's perspective where the head motions are being transformed into movements in the virtual environment. Recently, HMD, which used to be expensive and exclusively affordable by large companies, has become much more affordable even for individuals and have genuinely experienced a considerable advancement in the refresh rate needed to smoothly translate head movements in the virtual environment. It also now has an adequate resolution and a wider FOV that provides realistic impressions. These advancements have helped overcome the problems faced by the users when they wear the HMD especially virtual motion sickness experienced with longer exposures (Hilfert and König 2016). The VR system also requires both Hand-held Controllers for facilitating the navigation of the user within the immersive virtual environment, and usually two Bases that create the ambient VR environment. This integrated VR system works through tracking the head and body movements of the immersed person resulting in a sense of presence in the virtual space (Zaker and Coloma 2018).

In the construction industry, VR is experiencing a significant increase in use especially to facilitate communications among construction project stakeholders. The importance of VR in the construction industry is evident when some of the stakeholders are not fully familiar with the technicalities of the construction sector and therefore have no acquaintance with construction documents and technicalities. As professionals are usually trained to be capable to imagine and visualize their designs and express their ideas during the design process, this would be difficult for non-professionals and a non-specialized audience. Therefore, using 3D virtual models is beneficial in the building construction industry as it could efficiently replace several prolonged and sometimes even boring project presentation meetings (Hilfert and König 2016, Zaker and Coloma 2018). VR also proved towards being beneficial for the professional design process. In his study about the benefits of utilizing VR in the designing phase of the structural system, as a part of the overall building construction systems, Abdelhameed (2013) confirmed that the VR has increased the awareness of the designer about the structural properties and component assembly of the building structural system. The reason for that, is that the VR permits the designers to immediately interpret and evaluate the impacts of their design elements and components. VR also supports better comprehension of the integration between architectural, structural and construction systems on the building level.

In the following sections, this chapter first emphasizes the significance of VR integration in the Construction Engineering Education and Training (CEET) process. Then, it introduces the outcomes of a funded research project about investigating the potentials and challenges that would face the integration of VR, as a student's learning and self-assessment tool, in Building Construction (BC) education at the Architectural Engineering (AE) Program offered at the United Arab Emirates University (UAEU). It concludes with a proposed transformation process based on the utilization of VR in delivering BC courses and it also specifies the suggested actors, activities, tools, and expected outcomes of this process.

2. VR Significance in Building Construction Education and Training (CEET)

In their research, Smith and Saunders (2009) mentioned that there is a significant transformation in the job market, which necessitates effective incorporation of new learning techniques that could meet the needs of the skills of future professionals. They affirmed the current gap between the academic knowledge in educational institutions on the one hand, and the actual required professional knowledge by practitioners in the field of the construction industry, on the other hand. This came as a result of a national survey directed to both engineering employers and students. The results indicated that while almost half of the responding students who expressed their satisfaction with the academic preparation for the job market, only 18% of the employers in the construction field expressed their satisfaction with that. Here the use of VR as a cognitive tool is perceived as useful in bridging this gap and in helping preparing future professionals because it reduces the time needed to develop core visualization skills while allowing the improvement of problem-solving skills. VR would help respond to the industry requirement about enhancing the learner's ability to analyze, evaluate, and integrate complex construction systems, along with maximizing the provision for hands on experience.

In the field of education, VR is generally introduced as a support for 'Constructivism' due to its experiential nature where the learners construct knowledge mainly acquired from their virtual experiences. Instead of using human imagination, teaching through VR lets the users experience virtual situations in an active manner. Learning through this active engagement of the learners makes them more capable of retaining and recalling the gained knowledge more effectively if compared with the passive traditional educational methods. In addition, a big advantage in utilizing VR in education is that it widens the learning environment to include what would be impractical to associate with real situations. Accordingly, learners can explore different 'hypothetical' situations in the VR environment that simulate real context instead of just being confined with the limitations of the actual possible ones (Abdelhameed 2013). This would significantly enhance the education process especially when and where fewer actual site visits are available for students and trainees (Schott and Marshall 2018).

Younger generations of learners and trainees require introducing new approaches to pedagogy for them. These should be innovative approaches that encompass learning tools effectively serve these younger generations who have more visual and inductive learning preference (Schott and Marshall 2018). In accordance with this realization, in the early years of the new millennium VR technologies have started to be engaged in developing CEET programs with the aim to enable students to directly interact with the educational projects and objects within virtual three-dimensional (3D) environments. Obviously, these visualization capabilities have boosted the students understanding of the construction learning objects through where they are freely interacting with these objects in a way that drastically attracts and maintains their attention, especially if compared with the conventional methods of education and training such as "chalk-and-talk" and building physical mockups. Even using traditional 3D digital models in the CEET programs requires the use of the computer mouse or the keyboard to interact with the digital object form in a visually limited scale restrained by the size of the computer's monitor (Wang et al. 2018). Students usually prefer utilizing VR digital models over the traditional physical models because these virtual models help them to communicate their design concepts and components more convincingly with others. Virtual models could incorporate real field issues that enhance the students understanding of them through their ability to investigate the segments of the construction systems in the virtual model. Unlike the traditional learning method that requires students to have strong visualization skills, the VR model enables both the faculty and students to simultaneously engage in a discussion about the technicality of the learning process in the early stages of their design. Such advanced learning processes would certainly help students gain more skills that would facilitate their future careers in the construction industry (Smith and Saunders 2009).

Moreover, the VR experience gives the students and trainees a visual portrayal of clash detections or defects in any building design before the site construction phase starts. It also engages the intellectual, and sensual processes of the students that increases their motivation to learn and improves their problem-solving skills (Shelbourn et al. 2001, Smith and Saunders 2009). In addition, VR environment enables students to work together and interact with each other while they virtually experience a construction object or a project. It allows them to exploit and reuse information directly from the models in an interdisciplinary collaborative manner. It is maintained that the virtual interaction with a one-to-one scale 3D digital geometric models usually leads to active learner thoughts and better communication (Rahimian et al. 2014). Enhancing the students' teamwork and communication skills, increases the chances for their employability in the construction industry. Furthermore, VR models utilized in CEET programs might have advantages over real construction site visits because VR provides a safer way to experience the actual construction site, economizes time, and easily presents the construction project for a large group of students (Zaker and Coloma 2018, Samarasinghe et al. 2019).

Despite the noticeable growth of utilizing VR tools for improving the quality of construction education, especially as a virtual interactive construction education (VICE), some essential limitations are still experienced including that the VR systems are usually offline without the cooperation of educators, and that VR has not been incorporated appropriately with the traditional construction education processes. Furthermore, the level of interaction and mutual communication among users in VR is considerably low, and the class spaces required to operate VR systems appropriately might be limited (Le et al. 2015). With utilizing the most advanced VR devices, the authors investigated a case study of incorporating VR as an educational tool in a Building Construction course at the Architectural Engineering department, UAEU, as presented in the following sections.

3. VR as a Student's Learning and Self-Assessment Tool in Building Construction: A Case Study at the UAEU

The Architectural Engineering Undergraduate Program at the UAEU is internationally accredited by the Accreditation Board for Engineering and Technology known as ABET (ABET 2021). According to the ABET requirements, there are four areas that could be covered in accredited architectural engineering curriculum including: construction/construction management, building structures, building mechanical systems, and building electrical systems. By their graduation time, Architectural Engineering students should reach the synthesis/design level in one of these four areas, the application level in a second area, and the comprehension level in the remaining two areas. Accordingly, the AE program at the UAEU has defined the attainments levels for its undergraduate curriculum starting with the synthesis/design level in the (building) construction/construction management, followed by the application level in the building structure, then the comprehension level in both the building electrical and mechanical systems.

Because this chapter is concentrating on the utilization of VR in the Building Construction area, it is important to keep in mind the measures of the synthesis/design level, as per the ABET definition. The design, being related to one building system, should consider the other three architectural engineering systems. It should also work within the architectural design of buildings, include communication and collaboration with the whole building design and construction team members, utilize computer-based technology, apply relevant codes and standards, and finally consider sustainability aspects in the building design.

All the delivered courses of the AE undergraduate curriculum are tailored according to these levels of attainments. This makes Building Construction courses very essential in achieving the overall Program Learning Outcomes. Currently, the AE curriculum has three Building Construction Courses that starts with delivering the basics of Building Construction Systems in the first course, then, the Building Construction Components in the second course and the Advanced Building Construction Systems in the third course. The current traditional delivery method of all the three Building Construction courses includes PowerPoint lectures, smartboard instructions and some limited construction site visits. Meanwhile, the conventional teaching materials encompass textbooks, handouts, manuscripts for local and international building codes and standards, construction products catalogs, and video clips. The registered students in these, and actually all other similar AE courses, are still intensively relying on two-dimensional CAD drawings in preparing their assignments and term projects. As acknowledged from the students end-of-semester feedbacks and overall results, these conventional methods and tools have negatively affected their ability to fully comprehend the complexity of the structural systems and the building construction components they have studied. The students also could not appropriately undertake self-assessment of their building construction designs when relying on these 'flat-level' visual tools. As a result, the outcomes of these construction courses have not reflected the desired preparation of the gradates through acquiring state-of-the-art knowledge in the Building Construction industry. As mentioned earlier, Building Construction industry has recently adopted both of the Building Information Modeling (BIM) and Virtual Reality (VR) as combined tools aiming at increasing collaboration ability among project team members as well as reducing errors, detecting clashes, and correcting and flaws before the site construction begins.

3.1 Objectives and Investigation Tools

Given the significance of Building Construction courses in the AE undergraduate curriculum and in order to search for ways to bridge the gap between Building Construction education and industry, in 2019 a one-year funded research project by the UAEU was launched. The project, led by the main author as a Principal Investigator and four senior students participating as Research Assistants, aimed at examining the potentials and challenges that might face the integration of VR techniques in the field of Building Construction Education in the AE Undergraduate Program. In addition, from a wider perspective this research project is envisaged to contribute to the lack of attention paid to the virtual teaching systems of Building Construction education in general (Zhang 2013).

Building Information Modeling (BIM) was the first step in incorporating VR in this case study. This is because while reviewing the status quo of Building Construction industry, it has been noticed that BIM has become an essential pillar in developing Building Construction projects all over the world. In many cases, this integration has been supported by mandates and regulations such as in the UK where the Government announced its "Government Construction Strategy" that included a mandate for the implementation of BIM Level two on all public projects by 2016. Also, New York City has its BIM Guidelines since 2012 and the community of Catalonia since 2017 (Zaker and Coloma 2018). Accordingly, in this research project design, the BIM was the pillar of the VR integration in the building construction teaching and learning process and the four Research Assistant students participating in this project were selected among those who have a strong knowledge about Autodesk Revit software as the main BIM tool. Relying of the BIM model creation and an advanced VR Plug in for the Revit BIM software to generate the VR environment managed to eliminate the need for additional resources when creating the building construction 3D virtual models to help convert the model into a realistic visual representation of the building. This also significantly minimized the problem of incompatibility among the used software packages and saved time and effort that used be wasted when adapting the required changes into the VR model (Hilfert and König 2016).

The course ARCH 425: Advanced Building Construction Systems was selected to apply the transformation case study on it through changing from traditional delivery and assessment tools to the BIM-VR enabled ones. As per its description, this course aims at students' understanding of advanced building construction systems and methods as well as the prefabrication and modular structures. It also introduces advanced building structural systems, new materials and responsive technologies, advanced construction working drawing, and construction detailing all using computer-aided drafting tools. According to the Course Learning

Outcomes (CLOs), upon successful completion of this course students will be able to:

i. Acquire knowledge of advanced building techniques needed for better construction efficiency.
ii. Evaluate alternative advanced structure systems and materials and relate their studies to practical applications.
iii. Comprehend building components and their behaviors.
iv. Examine modular coordination in building design and construction systems rationally, logically and coherently.
v. Use architectural and structural knowledge in analyzing different technologies.

Among the several structural and construction systems taught in this course, four essential systems were selected to undertake the research project investigations. The prefabricated structure and long span space truss structure represented the advanced structural systems, while the masonry brick veneer cladding and glazed curtain wall represented the building construction systems. First, the Prefab system in building construction is a technique through which large units of a building are produced in factories to be later assembled as ready-made components in the building site. This technique permits the speedy construction especially for large structures. It has been applied mainly to modular buildings such as urban housing units. The importance of the prefab system stems from it the fact that it saves the excessive time usually needed for both the structural and finishing works in conventional construction methods. It also avoids wasting construction materials, messy construction site, and polluting the surrounding contexts. Prefab techniques allow for higher quality control within the factory environment, especially if compared with in site construction processes that would be affected with the climatic conditions and other site related problems. It also reduces the overall cost due to its mass production process and the less need for skilled labor in the construction site. Still, building Joints are the most critical aspects in the prefab techniques. Designed according to their position in building fabric, these joints could be wet using in-site grout, or dry using mechanical connections by bolt and nut or welding.

Second, the Space Truss system is a metal truss-like, lightweight rigid structure constructed from interlocking supports in a geometric pattern. With its high constructability the space truss structure system is mainly used in building structures to span large areas with few interior supports. Third, the Veneer Brick Masonry Cladding system is usually applied to reinforced concrete frame. The veneer layer is commonly erected brick by brick with conventional cement mortar, starting from a steel shelf angle that is attached to structural frame at each floor. While the construction process and details are essentially the same as for a masonry cavity wall of single-story building, but there are some differences including the need for a soft joint beneath each shelf angle to accommodate movements in the frame of the building without applying a structural load to the veneer brick masonry cladding, and the need to vertically divide the masonry curtain wall by movement joints to allow the frame and the masonry cladding to expand and contract independently of one another. Fourth, the Curtain Wall system is mainly composed of aluminum extrusions and double-glazed panels. The aluminum is the metal of choice for curtain walls because it protects itself against corrosion, it accepts and holds a variety of attractive surface finishes, and it can be fabricated economically into elaborately detailed shapes by means of the process of extrusion.

After defining these essential building construction systems and their related investigable issues, a consequential four stages method was adopted for defining the potentials and challenges of the transformation process of the course form a conventionally delivered course to a course relying on BIM and VR combinedly as teaching, learning and student's self-assessment tools. The tools were used to examine the students' comprehension about how the components of the selected structure and building construction systems are assembled together to form a complete system. Besides observing the resulting students' self-learning abilities of this transformative process, the involvement of the teaching instructors in the discussion of the investigated Building Construction model with that students was also monitored.

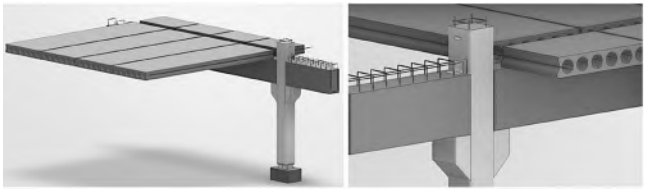
3.2 Stages of the Investigations

Stage A: Transformation of Building Construction Systems into BIM Models

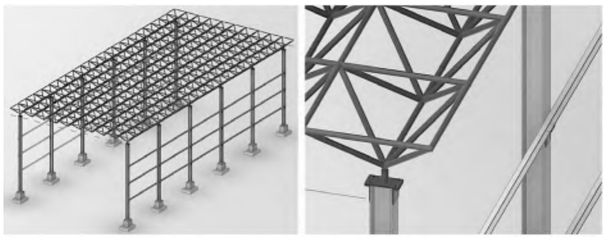
For preparing the VR versions of the studied building construction models, the research assistant students were assigned by the PI to transform the 2D structural and building construction components of the four selected systems into BIM models, relying on the experience they already gained from their previously studied design courses. Autodesk Revit was used as the BIM software with its acknowledged robust platform that offers an efficient model-based approach for designing constructions and buildings (Finances online 2019). Also, the software is free for students and instructors to download as an educational version.

The four building structural systems were developed into Revit-BIM models with as much accurate materials and details as possible. Figure 1a, b, c and d show the BIM developed models of these systems.

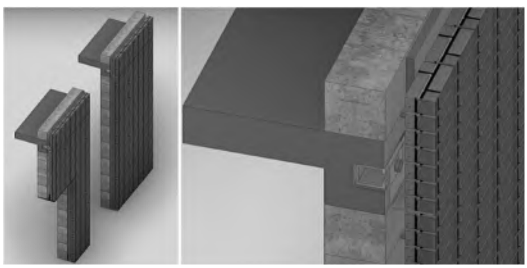
Despite the availability of the needed resources for creating BIM models, including the software and the hardware, this stage took longer time than expected. This is mainly because the research assistant students



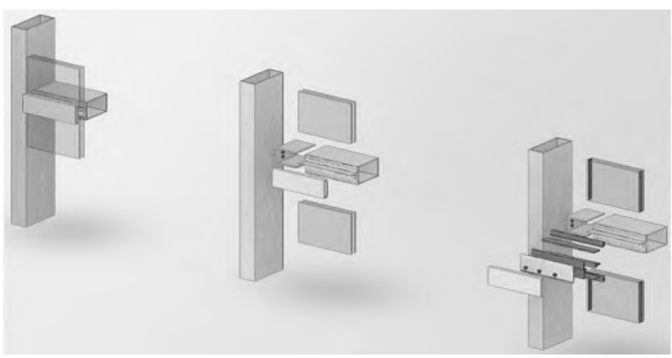
(a) Prefab construction system



(b) Space Truss construction system



(c) Masonry Brick Veneer Cladding construction system



(d) Glazed Curtain Wall construction system

Figure 1. BIM models for; (a) Prefab construction system, (b) Space Truss construction system, (c) Masonry Brick Veneer Cladding construction system, and (d) Glazed Curtain Wall construction system, as developed by the research assistant students.

lack the advanced skills for developing the details of the structural and building construction systems as their usage of Revit was inclusively in developing building 3D models in architectural design studios rather than as a detailing modeling technique. To overcome this technical difficulty the research assistant had to consult various tutorial materials to finally manage to develop the required systems in a satisfactorily manner.

Stage B: Transformation of BIM Models into VR Models

Afterwards, the research assistant students were directed to use the detailed BIM models to prepare the intended VR models. This was a straightforward process thanks to the used Enscape™ VR plugin for Revit with its real-time rendering. The building materials in this plugin are automatically converted into visually realistic materials. No technical difficulties were faced during this process except some glitches that were revealed when the generated VR models were inspected for verification. HTC Vive VR system on a gaming laptop was used for the verification and testing of the transformation process in the following third stage.

Stage C: Testing the VR Integration in Students Learning and Self-Assessment

The PI and the participating research assistant students tested the transformation method with a sample of senior AE undergraduate students who have successfully passed the course ARCH 425 as conventionally delivered. Twenty students accepted to voluntarily participate in testing this transformation process to investigate its usefulness to them as a learning and self-assessment tool. The voluntary senior students were subsumed into four groups where each group of five students was asked to experience one of the four defined construction systems comparatively using both the conventional then the VR techniques. To investigate the potentials and the challenges associated with the VR building construction models, the students were first theoretically introduced to each of the investigated systems using the same materials that they experienced in their ARCH 425 lectures. The aim was to refresh their minds about the assigned system as they originally learned it.

Afterwards, each student was asked to draw a sketch for a defined section in each of the four investigated systems as they conventionally perceive them to test their comprehension of the investigated system before experiencing the VR tool. Afterwards, with the guidance of the research assistant students, the interviewed student was asked to put on the VR headset to virtually explore the same building construction system but in the VR mode with its real scale and full details. After completing their virtual navigation, each student was asked to redraw the same sketch of the investigated system (Figure 2). This gave them the chance to not only be taught about the system but also to self-assess their own understanding of the components and fixation details of the investigated

Figure 2. Testing the VR transformation process with AE undergraduate students.

Table 1. Ratings of the students' opinions about VR utilization in advanced building construction systems.

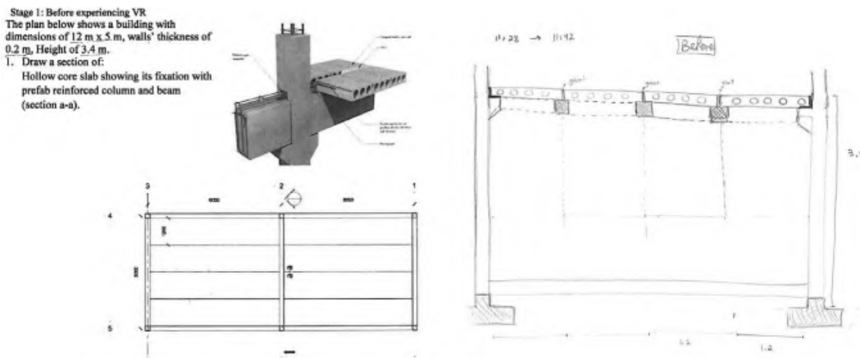
	Low	Average		High	
	1	2	3	4	5
Q1: How do you rate the change that the VR experience made to your knowledge about the components of the investigated system?	○	○	○	○	○
Q2: How do you rate the change that the VR experience made to your overall perception about the investigated system?	○	○	○	○	○
Q3: Are you willing to undertake your Building Construction assignments in BIM rather than CAD, then, experience them in VR?	○	○	○	○	○

building construction systems. Once they finished drawing the two sketches, the students were asked about their opinions through rating the usefulness of the VR techniques in the main three learning-related aspects as shown in Table 1. They were also asked to openly provide any additional comments after answering these questions to allow for extra probing in their experiences.

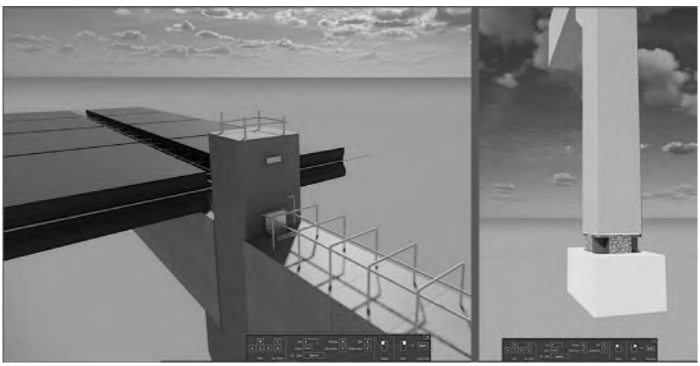
Stage D: Assessment Results of the Transformation Process for the 4 Selected Systems

I. Prefab System

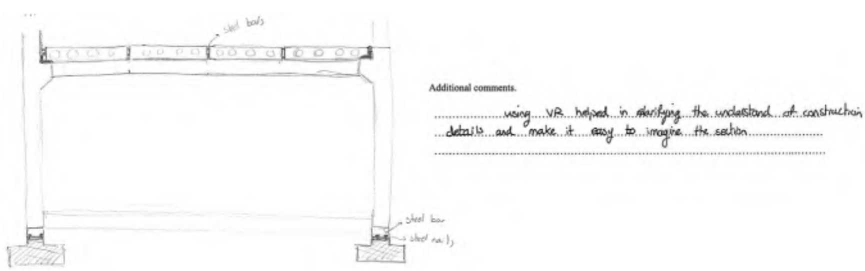
Figure 3 illustrates the results of the first investigated system: the prefab construction system. As shown in Figure 3a, the system was theoretically introduced to each of the five interviewed students, then the student drew the illustrated section sketch to demonstrate her understanding of its individual components and the system as a whole. Figure 3b depicts some screen shoots for the VR model of the system. While Figure 3c is the sketch drawn for the same section after the student experienced the VR model



(a) The Prefab construction system before experiencing the VR and a student's sketch for a section in it.



(b) The Prefab construction system in VR.



(c) A student's sketch for the same section in the Prefab construction system after experiencing the VR model.

Figure 3. (a) the Prefab construction system before experiencing the VR and a student's sketch for a section in it, (b) The system in VR, and (c) A student's sketch for the same section after experiencing the VR model.

of it in full. The difference between the two sketches is obvious where, thanks to the VR tool, the student managed to express her understanding more accurately for the whole system and its components.

Figure 4 below concludes the responses of the five students who investigated this model. Most of them highly rated the changes that the VR experience made to their knowledge about the components of the system and the change that the VR experience made to their overall perception about the system as a whole. Meanwhile, all of them expressed their willingness to undertake their building construction assignments in BIM, then, experience them in VR as this would give them the change for self-assessing their work.

As for the students' additional comments about the VR utilization in learning about the prefab construction system, a student mentioned that: "by seeing the details in VR, I could understand how all pieces are connected together". Another student commented that: "The details were very clear in the VR view. This is great!" But on the other hand, a couple of students raised some concerns. The first stated that "I am short sighted, so for me to wear the VR headset, I had to remove my glasses! This gave me a blurred vision, so I had to zoom in enough to be able to see". Another student mentioned that "the prolonged exposure to VR gave me some headache and dizziness".

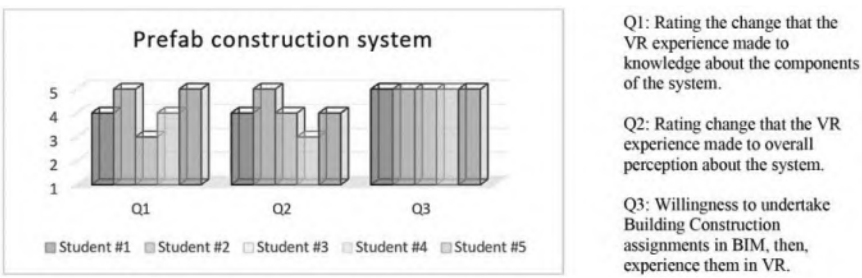
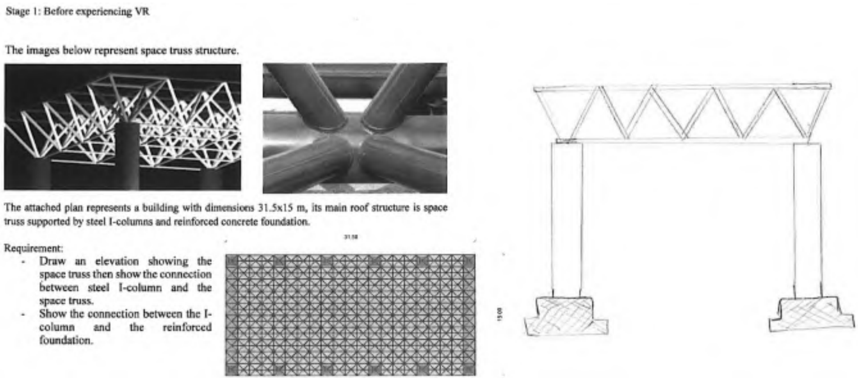


Figure 4. Interviewed students' answers on the questions about the usefulness of the VR tool in learning prefab construction system.

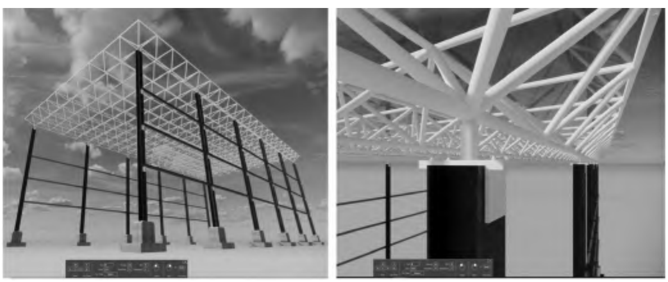
II. Space Truss

As in the first investigated system above, Figure 5 illustrates the results of the second investigated system: the space truss construction system. Similar interview procedures were followed as shown in Figure 3a, b and c. The difference between the two sketches is also distinctive where the VR has obviously helped the student to enhance her understanding of the components of the system and its entirety.

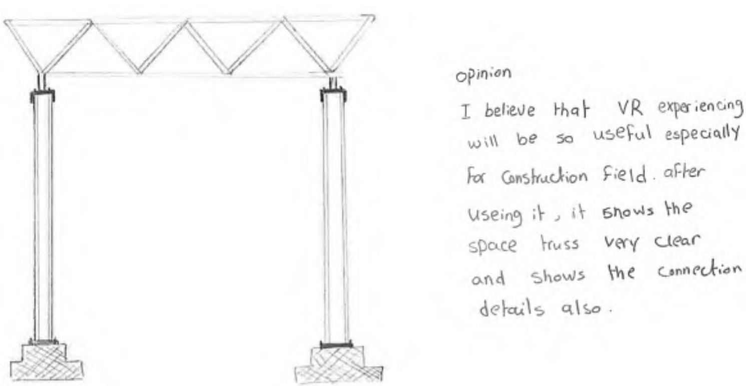
As shown in Figure 6, the interviewed students selected ratings that ranged between four and five out of five for the first two questions, while they rated the third at five.



(a) The Space Truss construction system before experiencing the VR tool and a student's sketch for a section in it.

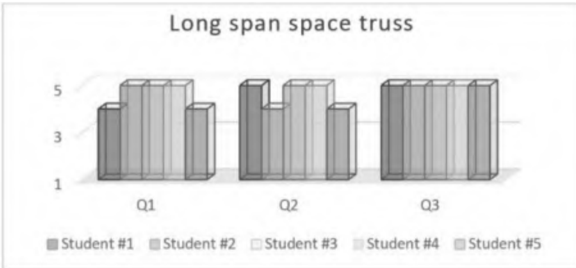


(b) The Space Truss construction system in VR.



(c) A student's sketch for the same section in the Space Truss after experiencing the VR model.

Figure 5. (a) the Space Truss construction system before experiencing the VR tool and a student's sketch for a section in it, (b) The system in VR, and (c) A student's sketch for the same section after experiencing the VR model.



Q1: Rating the change that the VR experience made to knowledge about the components of the system.

Q2: Rating change that the VR experience made to overall perception about the system.

Q3: Willingness to undertake Building Construction assignments in BIM, then, experience them in VR.

Figure 6. Interviewed students' answers on the questions about the usefulness of the VR tool in learning space truss construction system.

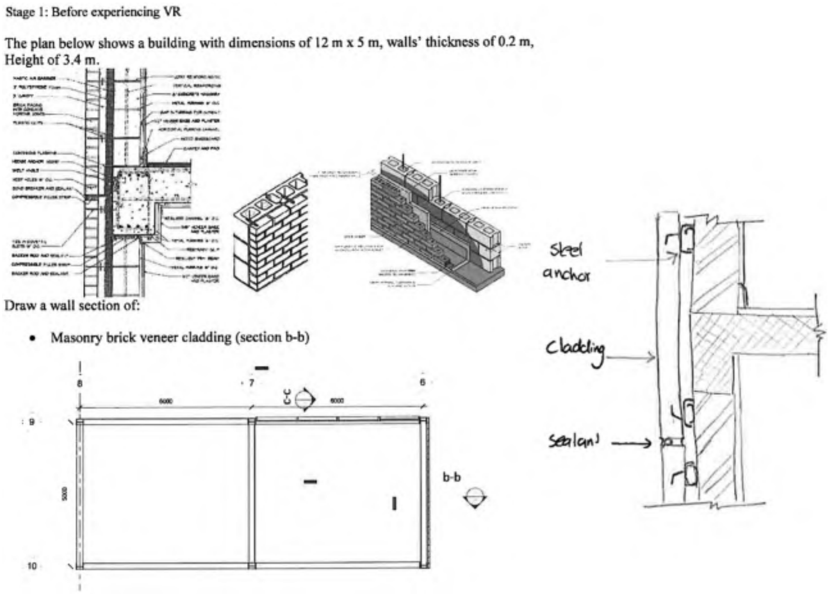
After this experience, an interviewed student mentioned that: "the VR allowed me to look at the details, so it gave me more understanding about the system compared to the 2D details. VR gave me also the chance to feel the real scale of the system." A second student added that: "This is an interesting way of learning, because it is much easier for me to comprehend the information. We hope to integrate it in all building construction courses". A third one commented that: "I believe that VR experience will be so useful especially for the building construction field. After trying it, it shows the space truss and its connection details very clearly."

III. Masonry Brick Veneer Cladding

For the third construction system, the Masonry Brick Veneer Cladding, the students' sketches before and after experiencing the VR (one example is provided in Figure 7) clearly proves the usefulness of it for the students' learning and self-assessment of the system.

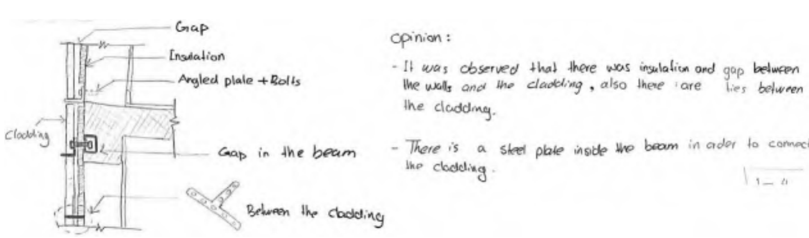
This is supported by the students' opinion where they rated highly all the three fields of the usefulness of the utilization of VR tool in learning about the building construction systems.

After undertaking the VR session, one of the interviewed students commented that "I clearly noticed the thermal insulation and the cavity between the wall and its veneer cladding. Also, I noticed the steel anchor channel inside the reinforced concrete beam that used to support the shelf angle." Another student added that: "The details are clearly showing in the VR model, and I understood how the various elements are connection together". A third student asked for some enhancement on the VR model for better understanding. She stated that "the metal ties connecting the brick veneer to the base wall are not clear in the VR. Also, I wish to see the foundation and a full floor section with its layers of finishing materials".



(a) The Masonry Brick Veneer Cladding before experiencing the VR tool and a student's sketch for a section in it.

(b) The Masonry Brick Veneer cladding in VR.



(c) A student's sketch for the same section in the Space Truss after experiencing the VR model.

Figure 7. (a) The Masonry Brick Veneer Cladding before experiencing the VR tool and a student's sketch for a section in it, (b) The system in VR, and (c) A student's sketch for the same section after experiencing the VR model.

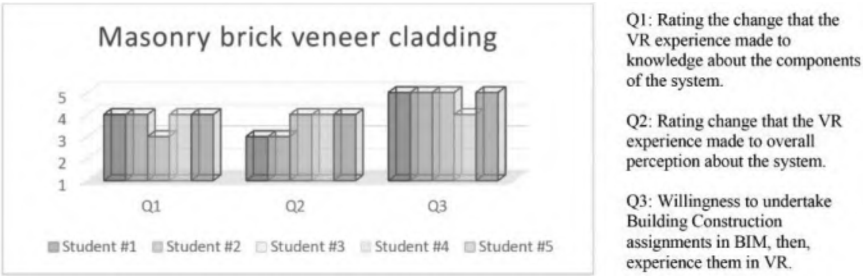


Figure 8. Interviewed students' answers on the questions about the usefulness of the VR tool in learning masonry brick veneer cladding construction system.

IV. Glazed Curtain Wall

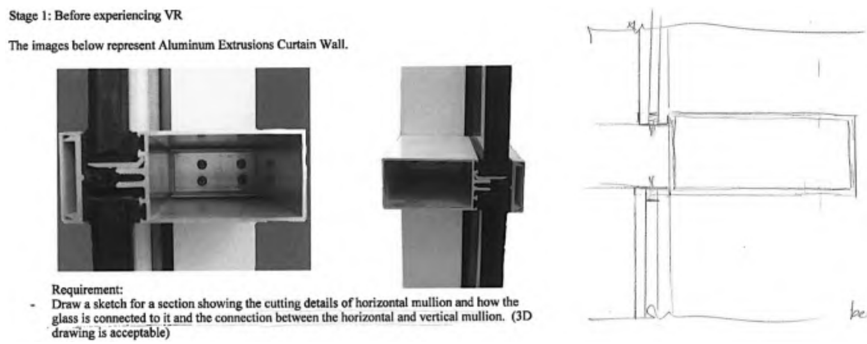
Figure 9 below shows an example of the outcomes of the sessions before and after experiencing the VR tool in exploring the Glazed Curtain Wall system. The sketches drawn after experiencing the VR reflect a deeper understanding of the system and its components.

As for the ratings, the majority of the interviewed students gave high ratings to the three aspects of usefulness as detailed in Figure 10 below but still a little bit less than the previous systems.

One of the students pointed out that "The VR made me understand how the glazing panel is connected to the rubber gasket and set block, and how the whole components of the system are connected together". A second student commented that: "The VR shows more details and element by element connections which makes it easy to understand and draw later." A third one commented that: "There is a very big difference after the VR. The connections are more visible for me now." A fourth student also commented that: "It is clearly showing how the glazed curtain wall system is fixed to floor slab. It changed a lot in my understanding about the detailing and increased the knowledge in how the pieces are connected together." Another student suggested that the department offer some workshops to teach the students how to make 3D details in BIM (Revit) so they can easily convert them to VR models.

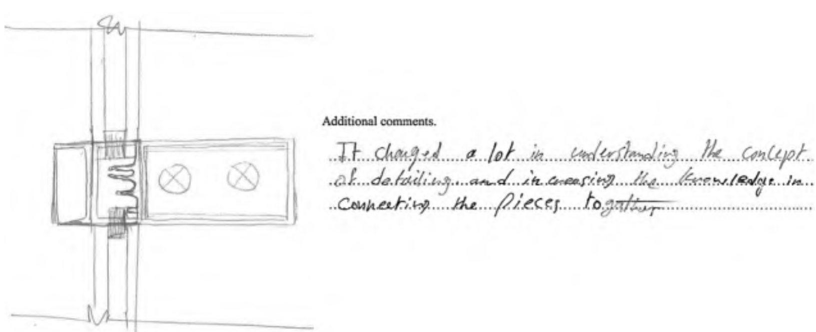
4. Concluding Remarks and a Proposed VR Integration Process

The outcomes of the research project have revealed the significant success of the VR with the BIM modeling in demystifying the components and details of complex and advanced building construction systems for Architectural Engineering undergraduate students. This evident effectiveness of VR and BIM as a combined students' learning and self-assessment tool could profoundly enhance the attainment of the CLOs for not only the investigated ARCH 425 Advanced Building Construction



a) The Glazed Curtain Wall before experiencing the VR tool and a student's sketch for a section in it.

b) The Glazed curtain wall in VR.



c) A student's sketch for the same section after experiencing the VR model.

Figure 9. (a) A student's sketch for a section in the introduced glazed curtain wall before experiencing the VR tool, (b) The system in VR, and (c) A student's sketch for the same section after experiencing the VR model.

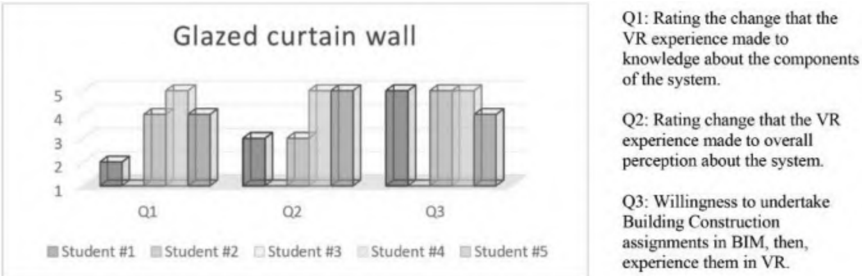


Figure 10. Interviewed students' answers on the questions about the usefulness of the VR tool in learning glazed curtain wall construction system.

Systems course, but for all other building construction courses in the AE undergraduate curriculum. The success of this VR-BIM combined tool could also compensate for real construction site visits that might not be possible due to exceptional circumstances such as the restrictions imposed by the Covid-19 pandemic and/or the harsh weather conditions in the country.

Based on the discussed outputs of the transformation of the course, a proposed process for the integration of the employed VR-BIM tool into the teaching and learning methods of building construction courses delivery method might be suggested as follows:

- First, in each of the three building construction courses, the registered students understand the theory of the introduced construction system and its components through the lecture delivered by the course instructor.
- Second, the students are to be asked to develop the explained building construction system and actually its components into a BIM-Revit full model (some limited ready-made Autodesk Revit software families are only allowed for complicated systems). The students are to be asked to develop as much BIM digital models as needed for each system showing its different compositions, joints and connections to explain the assembly method of the individual elements of each building construction system. This requires that the student has a solid background about using Revit as a BIM modeling system for building construction especially that they should add as much construction details and completed components in the initiated BIM digital models as possible. Actually, the participating Research Assistant senior students in this research project have shown good ability to enhance their skills of developing BIM digital modeling utilizing Revit software on their own relying mainly on the widely available free tutorial materials on the Internet.

- Third, through utilizing a VR plugin for the Revit BIM software, the students undertake self-assessment of their developed BIM digital models for the studied building construction systems and components. This requires the supervision, and as minimal help as possible, from the course instructor.

Figure 11 illustrates a diagram for this proposed process showing its actors (students, instructors, teaching assistants), activities (lecturing the theory for building construction systems, developing BIM models for these systems, developing VR models), tools (PowerPoint lectures, BIM modeling tool, VR devices, VR plug in), and outcomes (initial understanding of the building construction theory, better understanding while developing the BIM models, full comprehension through the VR tool, overall a better attainment for the course's CLOs, and virtual construction site visits).

It is envisaged that through applying this proposed process the gap, as described by Smith and Saunders (2009), between what the construction industry expects from architectural engineering graduates on the one hand, and what academia is actually producing on the other hand, will be bridged to a large extent. This will also contribute to the enhancement of the connections between construction industry and both the faculty and the students, especially with the fact that the building construction industry is rapidly moving towards full digitized immersive

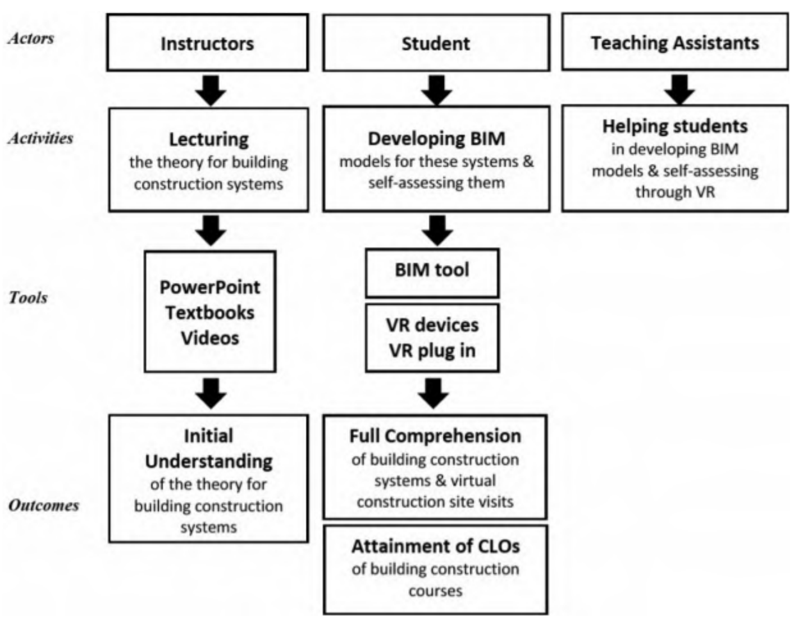


Figure 11. A diagram for the proposed VR integration process.

building construction techniques (Galal Ahmed 2020). Still, more effort is needed for the real improvement of architectural engineering curricula and especially in building construction to meet future workforce needs. The output of this research project also contributes to the active effort in producing research related to exploring the applicability of VR systems in university classrooms. Still, it is noteworthily mentioning that VR utilization was associated with some problems, as discussed in this research. Some students found wearing the HMD not comfortable, while others experienced some physiological problems such as headache and dizziness. But it is hoped that with more near future advancement in VR technologies these and other similar problems associated with the current use of VR systems will disappear.

As for the future trends in virtual learning tools in the field of building construction, both "Collaborative VR" and the Augmented Reality (AR) technology seem promising. First, the need for Collaborative VR has resulted from the high demand for transforming VR classroom-based teaching into online multi-user collaborative simulation that avails real-time teaching and better achieve the educational objectives of the Building Construction curricula. Known also as "Social VR", Collaborative VR has the potential to positively affect the student's accessibility to updated knowledge through distance learning that remotely connects the student with wide audience independently from the constraints of place and time and with significantly lower cost if compared with classroom-based VR techniques. This will also increase the student's collaborative and knowledge sharing skills that would enormously help them in their professional life. The call for adopting Collaborative VR is supported by an increasing number of dedicated digital platforms that are showing a strong potential in supporting experiential learning as a pedagogical tool in the field of building construction and construction project management. The idea is to provide a virtual place for many users to interact, explore various experiences and share knowledge among each other through using enactive role-play avatars. Through role-playing the instructors and the learners can synchronously and asynchronously collaborate via the avatars within an immersive VR environment in a way that improves the attainment of the learning outcomes especially those related to the real-life experiences (Le et al. 2015).

Second, despite the fact that AR lacks the full virtual environment design freedom without the boundaries of reality, but AR is highly expected to become an essentially important educational tool in the near future (Hilfert and König 2016). As mentioned by Galal Ahmed (2020), AR virtual construction site visits are safer and more cost effective. Facilitating remote AR site visits will give the students unlimited chance to virtually visit various construction sites all over the world, which in return will enhance the practical experience of all actors in the education process including besides the students, their instructors and the teaching assistants. As students will acquire the skill to interact and collaborate remotely, their employability is expected to ultimately increase in both the local and global building construction industry markets (Galal Ahmed 2020).

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9

A Virtual-Reality Based Study to Evaluate Efficiency of a Technology-Based Emergency Escape Signs in Complex Smart Buildings

Elisângela Vilar, Francisco Rebelo* and *Paulo Noriega*

1. Introduction

The needs of the occupants in terms of accessibility and safety have significantly increased with the changes in buildings use. With buildings becoming increasingly larger and more complex, their use is now so diversified that sometimes facilities combine the functionalities of a variety of structures such as, hotels, shopping centers, public transportation terminals, airports, and offices. Besides, wayfinding in emergency circumstances are generally not the main focus when such facilities are being designed. Additionally, many times, such as in interventions in historical buildings, renovations and changes in buildings' use, conflicting wayfinding situations may appear (Tomko and Richter 2015). These conflicting situations could be related to ambiguous situations that arise with the placement of exit signs in decisions points, when these are posted in opposition to the paths that could be mostly used by the buildings' visitors. Thus, studying those doubtful situations created by the incongruence between the architecture and the signage system could decrease problems related with emergency wayfinding, being able to satisfy some visitors' needs, and increasing their performance in a network of paths leading to different destinations.

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Emergencies (e.g., fire egress) in complex buildings are stressful situations that can provoke unexpected, undesired and sometimes unsafe behaviors from the users. Examples of this are the wrong decisions taken in following marked emergency routes, increasing the egress time over the limit, or even trapping the users inside the building. Thus, the need for evacuation support systems that take into account human behavior, as well as the influence of environmental affordances (i.e., cues in the environment that can attract the action of following that path), is crucial nowadays.

In this context, the present study aims to investigate the efficiency of technology-based exit signs as facilitators of the emergency evacuation process, namely when compared with the conventional static exit signs. So, the use of a new approach for exit signs and its effectiveness in directing people to a safe place even when facing critical/doubtful situations is investigated.

A critical situation with conflicting information was designed in which the environmental affordances (e.g., a brighter corridor) and exit signs, at decision points, were giving contradictory directional information. The contradictory information was manipulated by inserting static emergency signs or technology-based emergency signs pointing to the opposite direction of the corridors that were the most chosen by participants, according to results attained in a previous study from Vilar and colleagues (2013). A virtual building was designed and a Virtual Reality (VR)-based methodology was used for this study. The use of this methodology facilitates the manipulation and control of the variables, also allowing researchers to reproduce experimental conditions and test new ones with a low effort. VR-based methodologies also allow the exposure of participants to a stressful emergency situation without submitting them to a real hazard. Gamberini and colleagues (2003) studied the use of VR as a tool in research to study wayfinding behavior during emergency. Through variables manipulation, such as fire intensity and the initial distance to the emergency egress, the authors used VR to examine how people respond during a fire in a public library. According to their results, users seem to recognize a dangerous situation within the context of a simulation and readily produced adaptive responses, thereby indicating that VR is a suitable setting for emergency simulations.

2. Theoretical Background

2.1 Emergency Evacuation

Emergency evacuation can be understood as the movement of people from a hazard area to safe destinations (Abdelgawad and Abdulhai 2009). This movement is made via specific routes, which should be part of an evacuation plan. In this way, an emergency evacuation can be defined as the process of wayfinding in stressful situations, which should be assisted by environmental information, such as the definition of escape routes, signs, and maps.

According to Santos and Aguirre (2004), three main distinct analytical dimensions can be referred to in emergency evacuation behavior: (i) the physical location of the evacuation; (ii) the existing management of the site; and (iii) the social psychological and social organizational characteristics impacting the response of persons and collectivities that participate in the evacuation. The physical location can be understood as the total environment, from the hazard area and its configuration, until the safe zone, considering the evacuation routes. The management refers to procedures, and controls deployed at evacuation, including support devices (from conventional signs to smart systems that support technology-based emergency guidance).

For a successful emergency evacuation plan, these three dimensions should be aligned to provide congruent support to evacuees. An example of the problem with these three dimensions' misalignment is conflicting situations created when environmental characteristics contradict safety signs' information. Previous studies (e.g., Vilar et al. 2014, Vilar et al. 2013) showed that when the buildings' architectural elements act as environmental affordances, they can interfere with the occupants' behavioral compliance with emergency egress signs, decreasing the efficiency of the egress signs, and consequently increasing the probability of injuries.

Some authors (Kobes et al. 2010, O'Connor 2005, Purser and Bensilum 2001), divided the evacuation process into two main categories:

- Pre-movement process: Comprised of Cue validation/Recognition phase and Response phase;
- Movement process.

Purser and Bensilum (2001) stated that the pre-movement process begins when an alarm is triggered or at a cue, and ends when the occupant starts his/her travel to the exit or to a safe place. The cue validation/recognition phase begins with an alarm or cue, and ends with the occupants' first response. So, it is the awareness of danger by external stimuli. During this phase, occupants continue with their pre-alarm activities. The response phase is the response to danger indicators. It begins at the first response and ends when the occupants' movement to an exit starts. It is a decision-making period in which occupants carry out a range of activities—such as investigating the situation, alerting others, fighting a fire. Thus, this process depends upon hazard detection, provision of warnings, response to warnings (pre-movement phase), and pre-egress behavior (e.g., collecting belongings, seeking information, choosing an exit).

The movement process starts when the occupants' movement towards an exit begins, and ends when the occupants leave the building or find a safe place. In order to analyze this process, it is necessary to take into account the occupants' flow patterns through the escape routes, and the time required for the occupants to travel to a safe place (Purser and Bensilum 2001).

For many years, evacuation time was considered the basic measure to evaluate fire protection systems. However, when human behavior is considered, many underlying assumptions about occupants' behavior, with little or no basis in behavioral literature, have been made by engineers, architects and designers (O'Connor 2005). The author also gives as an example the often-cited assumption that occupants' immediately evacuate a building upon the sounding of the fire alarm system. Considering this, in recent years some authors (e.g., Gamberini et al. 2003, Gamberini et al. 2015, Mantovani et al. 2001, Vilar et al. 2013) have studied human behavior during emergency evacuations, to incorporate this dimension into the prediction models, evacuation plans, and in the design of the emergency signage.

Thus, to ensure users' safety in emergency circumstances, safety design should consider an interdisciplinary approach, involving architectural design, signage design, as well as ergonomics, human factors, psychology, and technology. Considering this, the primary focus of this paper is the relative influence of new paradigms for emergency egress signs, mainly considering smart systems that support technology-based signs in the evacuation behavior during the movement process, in order to provide data and tools for those responsible and engaged in promoting safety into complex buildings. Also, this study reports some meaningful findings that can encourage a revision on the standards for the design of safety information, mainly concerning the emergency egress signs.

2.2 *Support System for Indoor Emergency Evacuation*

A safety sign is an specific object that provides safety information through a signboard, a color, an illuminated sign or acoustic signal, a verbal communication or a hand signal (Occupational Safety and Health Administration – OSHA 2014).

Emergency escape signs are those that give information about emergency exits and can be single/static or multi-modal/dynamic. According to Duarte and colleagues (2014), generally, the method of communication for a static sign is passive, in contrast with dynamic sign that usually is multimodal as it uses more advanced technology.

In general, the most used safety signage systems for emergency exit in buildings comprise a static signboard (illuminated or not). They are a symbol-based type of signs, consistent with the European Directive 92/58/EEC (Occupational Safety and Health Administration – OSHA 2014). According to Duarte and colleagues (2010), efforts were made in order to harmonize European and American standards; thus, text panels are also being inserted on safety signs.

According to OSHA (2014), the emergency escape signs are a rectangular or square shape, with a white pictogram on a green background, with the green part taking up at least 50% of the area of the sign. When illuminated, the emergency escape signs luminous contrast must be appropriated to the environment in which the sign will be used, but without an excessive amount of light (producing glare) or poor visibility as a result of insufficient light. The signs are usually made of paper, metal, or plastic (Duarte et al. 2010), and must be placed where necessary (mainly at decision points) to inform people about the escape routes during an emergency.

Considering the acoustic information, acoustic signs should be continuous, having a sound level higher than the level of ambient noise. It also must be easily recognizable, particularly in terms of pulse length and the interval between pulses or groups of pulses. Verbal communication can be done by a speaker or emitter, considering short, simple and clear spoken or pre-recorded messages.

Signage is an important element during the wayfinding process (Conroy 2001) as it optimizes people's performance in finding their way in both, daily (Vilar et al. 2014) and emergency cirumstances (Mantovani et al. 2001). However, some studies have investigated the efficiency of emergency escape signs, and findings suggest that static signs generally have low compliance rates, mainly when the built environment presents doubtful route-choices (i.e., exit signs pointing to corridors with lower illumination levels versus a corridor with better lit corridors). The results of a previous study (i.e., Vilar et al. 2014) revealed worryingly low rates of compliance with static exit signs (about 30%) for the first decision point, with an increment of the compliance along the route. This happens because some architectural features can overlap the exit signs, influencing people's wayfinding decisions in a stressful situation (Vilar 2012). McClintock and colleagues (2001) argued that the reason why people generally do not notice emergency escape signs is that these are seldom used.

An alternative to static signage is using smart active systems, which are activated when an emergency occurs. According to Kim et al. (2018), a smart exit sign system is a type of technology-based guidance system for emergency escape usually based on a set of sensors that dynamically change the direction posted on the emergency escape sign to indicate the shortest safe evacuation path, allowing evacuees to avoid dangerous areas. Included in these smart active systems are, for instance, doors that can open and close when activated during an emergency, and technology-based signs that can be dynamic, adaptable and/or interactive. They can be available on building sites, for example, as sensors and dynamic signs. It is a relatively new concept for emergency escape sign design, so few systems were already proposed and tested (e.g., Gorbil and Gelenbe 2011, Li et al. 2009, Moon and Seong 2011, Seo et al. 2008).

Kim et al. (2018) proposed a serverless smart exit sign system, in which communication between exit signs nodes are made using a wireless sensor network without a central server. Authors argued that main advantage of this type of smart system is reliability. They are more reliable than server-dependents ones as the entire system doesn't fail if the central server breakdowns. The same is for the exit signs nodes, which still communicate with neighboring nodes even if some of them are damaged. The installation of this type of smart system is also easier due to no need of wiring work, so it can be installed in an existing building. The developed prototype is composed of four modules: a light detection module, a wireless communication module, a microcontroller module, and a display module.

Additionally, technology-based signs can be designed as an interactive system that delivers safety information directly to users' portable devices based on environmental information acquired by sensors. Some examples are available, such as the system presented by Gorbil and Gelenbe (2011). It is an autonomous emergency support system based on opportunistic communications to support emergency evacuations. According to the authors, it was done considering low-cost human wearable mobile nodes allowing the exchange of packets at a close range of a few to some tens of meters with limited or no infrastructure. In this way, their proposed emergency support system uses opportunistic contacts between wireless communication portable devices to gather information regarding the current situation and disseminate wayfinding messages to promote safe evacuation.

Some authors (e.g., Wogalter and Mayhorn 2006, Wogalter and Mayhorn 2005, Mayhorn and Wogalter 2003, Smith-Jackson and Wogalter 2004, Wogalter and Conzola 2002) described how this technology could produce better warnings and signs; however, there is little information about their application for buildings and their efficiency in buildings.

Some studies have examined the effect of dynamic features in signs on behavioral compliance during work-related tasks and an emergency egress (e.g., Nilsson 2009, Duarte 2010, Duarte et al. 2010, Duarte et al. 2014). According to Nilsson (2009), flashing lights at emergency exits, as a dynamic feature, can potentially optimize the evacuation of buildings.

The design aspects of flashing lights at emergency exits, namely the color of the light source, the appearance of the light, and the location of the light fundamental aspects to consider when designing emergency escape systems. In this way, Nilsson (2009) pointed out that dynamic signage with flashing lights should have a green color, and lights should be placed at both sides of the exit sign. Findings of a study conducted by Duarte (2010) suggested that, for un-cued signs, dynamic presentations produced higher behavioral compliance than static ones.

Baker (1976) defined learned irrelevance as the inability to effectively respond to previously irrelevant information. McClintock and colleagues (McClintock et al. 2001) argued that learned irrelevance could impact human behavior in emergencies in buildings because it could cause occupants to ignore safety information (e.g., exit signs) that is available and they can see every day but never use. These authors tested an alternative design for emergency exit using blue flashing lights combined with European Back-lit emergency escape sign. The proposed design was compared with others through a questionnaire-like survey. Responses revealed that the proposed design was preferred amongst the participants and had the highest attention capturing ability.

For this study, technology-based signs using smart exit systems were considered, and dynamic images are available only in the case of an emergency, to avoid learned irrelevance. The projected image used was the "running man", however, the image size was augmented to increase the conspicuity of the sign (Figure 6). The behavioral compliance with the emergency escape technology-based sign is the main focus, and the efficiency of this type of signage system in a conflicting situation is investigated considering mainly the human behavior during emergency wayfinding in complex buildings. A conflicting situation was designed in which environmental variables (i.e., corridors width and brightness) and exit signs at decision points, were giving contradictory directional information (i.e., in a two-way intersection, one of the available paths was brighter and wider than the other, attracting participants to it. However, an exit sign was placed pointing to the opposite direction, a darker and narrower corridor). Conflicting situations were considered with the intention of testing exit signs in the highest complexity occurrence. To conduct the study, a virtual building (i.e., a virtual hotel) was designed and a Virtual Reality (VR)-based methodology was used to facilitate the manipulation and control of the variables, as well as to allow the exposure of participants to a stressful emergency circumstance, with fire, without submitting them to a real hazard.

In studies investigating evacuation times in buildings—Shih et al. (2000), in a VR-based study, and Xie and colleagues (2012), in a real world experiment—verified that, in some situations, people followed routes that were different from those indicated by the egress signs. In addition, these studies found that, generally, regardless of the presence of signs and smoke, people tried to return to the direction they first entered the building. The influence of the environment over behavioral compliance with exit signs was also found by Tang et al. (2009). In their study using VR, they reported that when participants were faced with seemingly contradictory information in the form of both an exit sign and an exit door, almost half of the persons choose to proceed through the door rather than follow the directions posted on the sign. Vilar and colleagues (2014) also verified that the environmental features could influence emergency signage effectiveness. In this study, authors found that during an emergency circumstance, even with static emergency escape signs available, people initially tended to not to follow the direction posted on signs, being attracted by environmental features.

Thus, the present study expands on the previous one conducted by Vilar (2012) investigating the use of a new approach for exit signs and its effectiveness in directing people to a safe place even when facing critical or doubtful situations. Given the goals of the current research as well as the theoretical background, the central hypothesis is formulated: Behavioral compliance close to 100% can be achieved when technology-based emergency escape signs are adopted, even when conflicting situations are considered.

3. Method

3.1 Design of the Experiment

The study used a between-subjects design, and two experimental conditions were considered:

- Control – With conventional static emergency escape signs;
- Experimental – With technology-based emergency escape signs.

The participant route-choice at pre-defined decision points, comprising 12 corridor intersections, and the evacuation time were the dependent variables.

3.2 Participants

Fifty-eight volunteers were randomly distributed across the experimental conditions:

- Control: Twenty-nine participants, 15 females and 14 males, aged between 18 and 35 years (M = 21.90, SD = 3.78);
- Experimental: Twenty-nine participants, 14 females and 15 males, aged between 18 and 28 years (M = 21.17, SD = 2.40).

All participants were asked to sign an informed consent form and were aware about side effects related with the use of VR, such as cybersickness. Color vision was screened with Ishihara's *tests for color-blindness* (Ishihara 1988) and all volunteers had regular color vision. All participants also reported regular sight or had corrective lenses. They also reported no physical or mental conditions that would prevent them from participating in a VR simulation.

3.3 Conflicting Situation

The conflicting situation was created considering the existence of contradictory information that was manipulated by inserting static emergency signs or technology-based emergency signs pointing to the opposite direction of the corridors that were mostly chosen by participants. The most chosen corridors were selected from a previous study carried out by Vilar and colleagues (2013) about navigational choice preferences associated with environmental variables (i.e., corridor width and brightness). These environmental variables were considered by the authors as attractors because they could influence participants' behavior, attracting them to choose a specific route instead of the other one. For the current study, only 12 corridor intersections (Figure 1) of the fifty-seven different situations studied earlier were selected. Corridor selection followed the following criteria:

i) the most chosen corridors considering the available alternative corridors (i.e., left vs. right, front vs. left, and front vs. right) for each situation (i.e., only corridor width, brightness enhanced in the wider corridor and brightness enhanced in the narrower corridor);

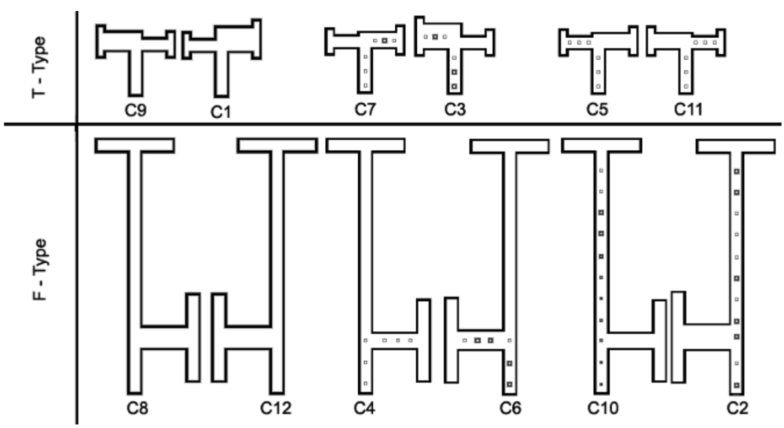

Figure 1. The 12 "T-type" and "F-type" corridor intersections selected from Vilar and colleagues (2013). Small squares represent lights.

Table 1. Percentages of choice for the 12 most chosen corridor intersections from Vilar and colleagues (2013) used as the basis for the emergency escape signs placement.

Corridor intersection	**Variable (attractor)**	**Direction**	**% of choices towards the attractor**
C1	Width	Right	72.05
C2	Brightness	Front	75.83
C3	Brightness and width	Left	87.87
C4	Brightness and width	Right	89.58
C5	Brightness	Left	81.67
C6	Brightness and width	Left	91.25
C7	Brightness and width	Right	89.58
C8	Width	Right	63.75
C9	Width	Left	72.92
C10	Brightness	Front	78.33
C11	Brightness	Right	83.68
C12	Width	Left	57.50

ii) the intersection type (i.e., "T-type" and "F-type");

iii) the narrower corridor when the difference across the percentage of choices was less than or equal to 1%.

Choices percentages towards a direction attained by Vilar and colleagues (2013) for the 12 corridor intersections used in this study are presented in Table 1. The percentages were also used as the basis for placing the emergency signs.

3.4 Virtual Environment (VE)—The Hotel

For this study, a virtual environment representing a virtual hotel and convention center already applied in a previous study (Vilar et al. 2014) was used. So, the same 12 corridor intersections previously selected (Table 1) from Vilar and colleagues (2013) were used in a building floor plan with three sections. For more details, see Vilar and colleagues (2014). Each section was designed to have the same travel distance, regardless of participants' directional choice at each decision point (Figure 2). The scenario considered was a person who is arriving late for a presentation at an important meeting at a hotel and convention center. Fire and smoke was inserted into the VE to create the emergency situation in the second floor (Figure 3).

The experimental conditions were created considering two emergency directional systems composed by static escape signs (control condition) and by technology-based emergency escape signs (experimental condition).

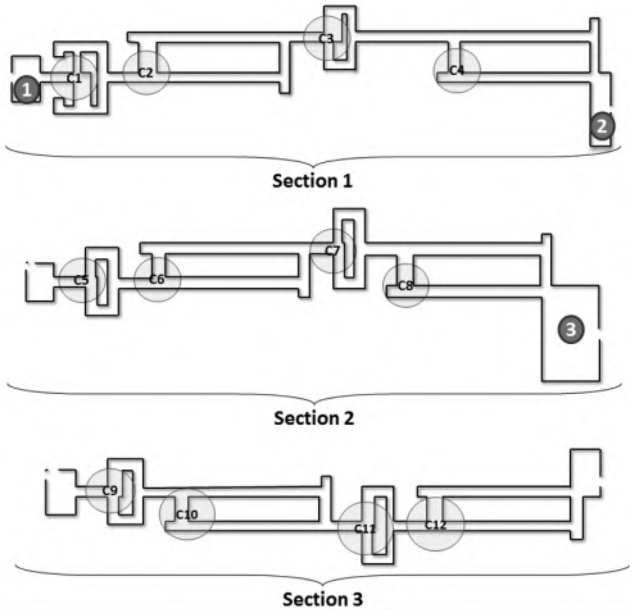

Figure 2. Top view of the floor plan with the three sections and with the location of the 12 selected corridor intersections. Numbers 1, 2 and 3 show where the wayfinding instructions were delivered to the participants.

Figure 3. Examples of fire with smoke on the second floor of the VE during the emergency situation.

Static escape signs are symbol-based and consistent with the European Directive 92/58/EEC standard required by law to illustrate an arrow and running figure to doorway (Figure 4).

Technology-based emergency escape signs used for the experimental condition were developed by a design team, considering a Human-centered design approach. This is based on a smart active system that projects an animated image on the wall when an emergency occurs. So, the image is only available when it is necessary, to avoid learned irrelevance (McClintock et al. 2001).

Figure 4. Static directional emergency escape signs usually used in buildings, and considered for the control condition.

The image is the "running man" as pointed by the European Directive 92/58/EEC, however the image size was exaggerated to increase conspicuity. A behavioral intention test (Wogalter and Dingus 1999) was also performed with 30 university students. For this, an animation with the designed technology-based emergency escape sign was presented to the participants and they had to answer two questions: (i) What does this sign mean? (ii) What would you do if you see this sign? Most of the participants (67.2%) considered the sign an emergency escape sign. Most of them (76.6%) also reported that if they saw the sign they would follow its direction through an emergency egress. Screenshots of the static exit sign (Control condition) and the technology-based exit signs (Experimental condition) placed on the virtual hotel can be seen in Figure 5 and Figure 6.

Figure 5. Screenshot of the control condition with the static emergency exit sign.

Figure 6. Screenshot of the experimental condition with the technology-based emergency exit sign.

To create the critical situations, the signs were always positioned to point to the directions opposite to those that were considered the most probable choice (see Table 1), according to the results of the study conducted by Vilar and colleagues (2013).

3.5 Scenario and Wayfinding Task

The same scenario used in a previous study (Vilar et al. 2014) was considered for this one to increase the participant's involvement. The scenario was based on a person who is late for a presentation in an important meeting at a hotel and convention center. A cover story, at the beginning of the experimental session, and three wayfinding tasks, during the VR interaction, were given to the participants. For more details, see Vilar and colleagues (2014). Participants were told that they should behave as they would in a real-life situation. The three wayfinding tasks conduced participants along a series of corridor intersections until they reach the elevator that leads to the second floor. When participant reached the second level, where the presentation is to occur, a fire is triggered, and he/she can see flames and smoke. An auditory alarm was also present. Figure 3 shows screenshots of some fire locations within the building.

3.6 Experimental Settings

Participants visualized a stereoscopic projection through active shutter glasses (i.e., MacNaughton Inc.'s APG 6000). For this, a stereoscopic projector (i.e., Lightspeed DepthQ 3D) was used. The projected image size was 1.72 m (59.7° of horizontal field-of-view—FOV) by 0.95 m (35.2° of vertical FOV) with an aspect ratio of 16:9. The observation distance was 1.50 m. The room (Room 1 at Figure 7) where the experiment took place

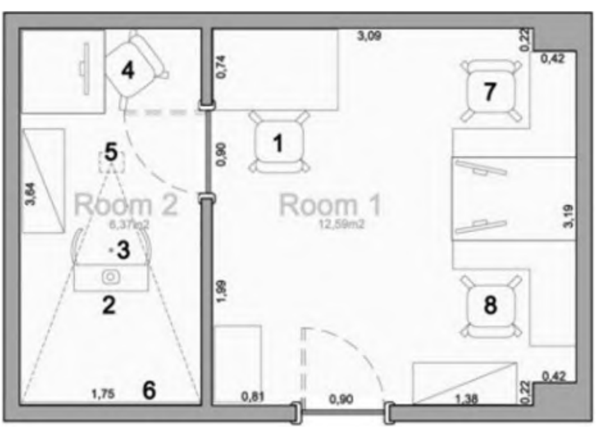

Figure 7. Plan of the virtual reality lab where data was collected, with the described locations.

had 1.75 m × 3.60 m of dimension. The screen in which the VE were project was at the smallest wall (point 6 of Figure 7), and all room was painted black to avoid reflections and distractions.

A Logitech® Attack™ 3 joystick was used as an input device to collect the participants' directional choices. The speed of movement gradually increased from stopped (0 m/s) to a maximum speed of 3 m/s. Wireless headphones (i.e., Sony® MDR – RF800RK), allowed the participants to listen to instrumental ambient music, the wayfinding tasks instructions given orally by the virtual characters, and the sounds of a fire siren and fire.

3.7 Procedure

Participants were received by the researcher at Room 1 (Figure 7) where a consent form was given to all participants before starting the experimental session, informing them about the procedures and eventual side effects. All participants agreed with the consent form and signed it. All participants were also informed that they could stop their participation at any time. Subjects participated individually in the experimental session. The average duration of the entire experimental session was approximately 30 minutes, divided into a training session and a VR-based component. Participants were told that they should fulfil the given tasks as accurately and as quickly as possible and they should behave as they were in a real situation. In addition, participants were unaware of the real objective of the experiment; they were told that the objective was testing a new VR-system. After the fulfillment of the consent form, participants started in a training session, at Room 2. For this, participant was placed at point 3 of Figure 7, in front of the joystick (point 2) and the screen (point 6).

The training session was a VE with a set of zigzag corridors and participants were encouraged to explore freely and navigate in a training VE, as quickly and efficiently as they could, without time restrictions. It was considered in order to (i) to familiarize participants with the simulation setup; (ii) to allow them to practice the use of navigation and visualization devices, to bring their virtual movements closer to their realistic/natural actions; (iii) to homogenize differences in participant's performance using a joystick; and (iv) to make a preliminary check for symptoms of simulator sickness (participants were asked to report whether they felt any discomfort). The researcher stayed in room 2, at point 4 during the entire session, and monitored participants' control of the navigation device by verifying their accuracy in executing some tasks, such as circumnavigating a pillar placed in the middle of a room without bumping into it and walking through the zigzag corridor without touching the walls. Participants were also instructed to inform the researcher when they felt relaxed and comfortable with the equipment. Only after verifying some of these equipment-related skills the researcher permitted the participant to start the VR-based component. No dialogue between the participant and the researcher was allowed after the simulation started.

The interaction started on the ground floor of the virtual hotel and convention center, at the reception, where participants received the first wayfinding task from a virtual character that was present in the VE. Along the way, participants still received two more wayfinding tasks from different virtual characters. The last task sent the participants to the second floor of the building via an elevator. Once they exited the elevator, an auditory alarm sounded, and flames and smoke appeared behind them, preventing further elevator use. Thus, participants were faced with finding an emergency egress point by navigating through the second floor to escape from the fire.

A controlled navigation approach was considered. For this, the corridors already passed by the participant were closed by doors on the ground level and by fire and smoke in the second floor. Thus, for each decision point, when participants chose one of the two alternative corridors, the corridor of the path that was not chosen was closed by a door (or fire), forcing them to continue along their initial selected path.

If the participants reached a time limit of 20 minutes inside the simulation, the experimental session was stopped to prevent eye fatigue, or simulation sickness, or both. Simulator sickness was mainly evaluated through participants' verbalizations. Researchers also monitored them during the interaction for symptoms such as redness of the face, nausea, dizziness and sweating (Kennedy et al. 1990, Keshavarz and Hecht 2011). At the end of the experimental test, a post-task questionnaire was used to collect demographic information such as age, gender, occupation and dominant hand. Participants were also asked to answer, using a seven-point scale format, questions related to their level of presence and overall involvement during the interaction with the simulation.

3.8 Measures

The measures obtained in this study can be grouped in three sets: (a) Behavioral measures, related to participants' behavioral compliance with emergency escape signs; (b) Performance measures, which correspond to the time taken (evacuation time) and the distance traveled in the simulation; and (c) Subjective measures, related with level of presence and involvement during the VR interaction.

Participants' behavioral compliance and performance measures were automatically collected by the VR system, and were used to analyze the efficiency of the emergency signs. Behavioral compliance represents the number of times the participants followed the direction posted in the exit sign. Subjective measures were collected through a post-hoc questionnaire adapted from the Witmer and Singer Presence Questionnaire (Witmer and Singer 1998). It was a multipart questionnaire, with 7 point Likert-type scale. All the items were communicated in Portuguese. English translations are provided in the current paper (see Table 2). A subjective measure, namely, the sense of presence, was used as control variable. It is expected that participants present similar levels of presence in both conditions (i.e., control and experimental conditions).

4. Results and Discussion

Criteria for presenting results are related to the choices favoring the direction pointed by the signs considering the experimental conditions (i.e., Control and Experimental). Only the data related to the second floor (emergency circumstances) were analyzed. All statistical analyses were conducted using IBM SPSS v.20. The statistical significance level was set at 5%.

Presence was analyzed as the control variable since it is expected that participants present similar levels for both conditions. According to a 7-point Likert scale (with 7 indicating the highest level of presence), overall the median values of presence in the VE ranged from 3.00 to 6.00. To ascertain whether there were significant differences between control and experimental conditions in the participants' perceptions, Mann-Whitney tests were conducted. As expected, no statistically significant differences were found regarding the quality of sensorial experience ($U = 386.50$, $p > .05$, $z = -.539$), quality of the interaction ($U = 408.00$, $p > .05$, $z = -.203$), distraction factors ($U = 347.50$, $p > .05$, $z = -1.161$), realism level ($U = 384.50$, $p > .05$, $z = -.577$), notion of time ($U = 413.00$, $p > .05$, $z = -.119$), and enjoyment level ($U = 319.50$, $p > .05$, $z = -1.597$). Accordingly, both conditions present same levels of presence, allowing the comparison of results attained after the interactions.

4.1 Participants' Behavioral Compliance with Emergency Signs

Participants' total route compliance considered the directional choices recorded for the entire route (12 corridor intersections). Table 2 summarizes the results obtained for all conditions. The corridors are presented according to their disposition on the building plan.

A chi-square test of independence was performed to examine the relation between participants' route-choices favoring the direction posted by the sign and the emergency sign type for the 12 corridor intersections individually. The relation between these variables was significant for the corridor intersections C1 ($X^2(1) = 23.727$, $p < .01$), C2 ($X^2 (1) = 9.087$, $p < .01$), and C3 ($X^2 (1) = 10.653$, $p < .01$). Nonetheless, the percentage of compliance in all the other analyzed corridors was higher

Table 2. Results considering the predicted directions from a previous study (Vilar et al. 2013), participants' total route, percentages of choices contrary to and favoring the posted emergency signs in control and experimental conditions. Corridors were arranged according to their disposition on the building's plan.

Corridor (intersection type)	**Variable (predicted attractor)***	**Variable direction***	**% of choices toward the attractor***	**Experimental conditions**			
				Control		**Experimental**	
				% choice contrary to sign direction (N)	**% choice favoring sign direction (N)**	**% choice contrary to sign direction (N)**	**% choice favoring sign direction (N)**
C1 (T)	Width	Right	72.0	69 (20)	31 (9)	6.7 (2)	93.1 (27)
C2 (F)	Brightness	Front	75.8	34.5 (10)	65.5 (19)	3.4 (1)	95.6 (28)
C3 (T)	Brightness and width	Left	87.9	31 (9)	69 (20)	– (0)	100 (29)
C4 (F)	Brightness and width	Right	89.6	6.9 (2)	93.1 (27)	– (0)	100 (29)
C5 (T)	Brightness	Left	81.7	13.8 (4)	86.2 (25)	– (0)	100 (29)
C6 (F)	Brightness and width	Left	91.2	17.2 (5)	82.8 (24)	3.4 (1)	96.6 (28)
C7 (T)	Brightness and width	Right	89.6	24.1 (7)	75.9 (22)	3.4 (1)	96.6 (28)
C8 (F)	Width	Right	63.7	17.2 (5)	82.8 (24)	– (0)	100 (29)
C9 (T)	Width	Left	72.9	6.9 (2)	93.1 (27)	– (0)	100 (29)
C10 (F)	Brightness	Front	78.3	6.9 (2)	93.1 (27)	– (0)	100 (29)
C11 (T)	Brightness	Right	83.7	6.9 (2)	93.1 (27)	– (0)	100 (29)
C12 (F)	Width	Left	57.5	6.9 (2)	93.1 (27)	– (0)	100 (29)
Participants Total Route Compliance (%)				20.1	79.9	1.4	98.6
SD				17.5	17.5	2.3	2.3

* Predicted results were attained from Vilar and colleagues (2013) study.

for the Experimental condition, differences were not statistically verified ($p > .05$). Thus, technology-based emergency escape signs were more likely to be followed by the participants when seen from the first to the third time than static emergency signs. It is important to notice that missing the first available sign when an emergency alert starts could represent to increase the distance traveled and evacuation time, also increasing the chance of physical damage. In this sense, the attained result is distressing, considering that, when static emergency escape signs are used, only about 30% of the occupants would begin the evacuation route by the right (planned by the emergency plan) path. It is worst when rates of compliance remain low for the second and third signs. With a change of a design paradigm, these rates had great improvement, reaching, as hypothesized, a ceiling effect.

4.2 Performance Measures

As for performance variables, evacuation time and distance traveled were analyzed in both conditions. All performance measures were considered from the moment that the auditory alarm started. For the condition with technology-based emergency signs (experimental condition), this moment coincided with the beginning of the projection of the exit sign on the wall. Table 3 summarizes the attained results.

Table 3. Descriptive statistics, Mean (M) and Standard Deviation (SD), for the performance measures across the experimental conditions.

	Evacuation time in seconds – M (SD)	**Distance travelled in meters – M (SD)**
Control group	203.90 (47.84)	560.40 (83.75)
Experimental group	173.38 (37.22)	513.56 (48.10)

4.2.1 Evacuation Time

Mean Evacuation time was lower for the experimental group ($M = 173.38s$; $SD = 37.22$; $SE = 6.91$) compared with the control group ($M = 203.90s$; $SD = 47.84$; $SE = 8.88$) (Figure 8). In order to ascertain whether there were significant differences in evacuation times between the control and experimental conditions, an independent-sample t-test was conducted. According to the results, the observed differences between the mean evacuation time from the experimental groups are statistically significant ($t\ (56) = 2.711$; $p < .01$; 95% CI [7.97, 53.06]). Considering this, participants had lower evacuation times when technology-based emergency signs were presented, staying, on average, between 53s and 8s less time exposed to the danger when compared to those who were exposed to the control condition.

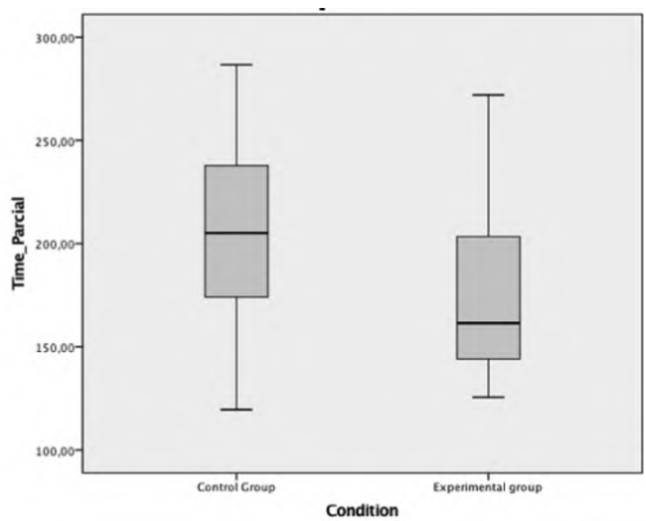

Figure 8. Boxplots for evacuation time by experimental condition.

4.2.2 Distance Traveled in the Simulation

Even in a controlled navigation setup (i.e., participants unable to walk around due to some paths closing behind them), mean distance travelled in the simulation was lower for the experimental condition (i.e., technology-based emergency escape signs) (M = 513.57 m; SD = 48.10; SE = 8.93) than for the control condition (i.e., static emergency escape sign) (M = 560.04 m; SD = 85.75; SE = 15.55) (Figure 9). An independent-sample

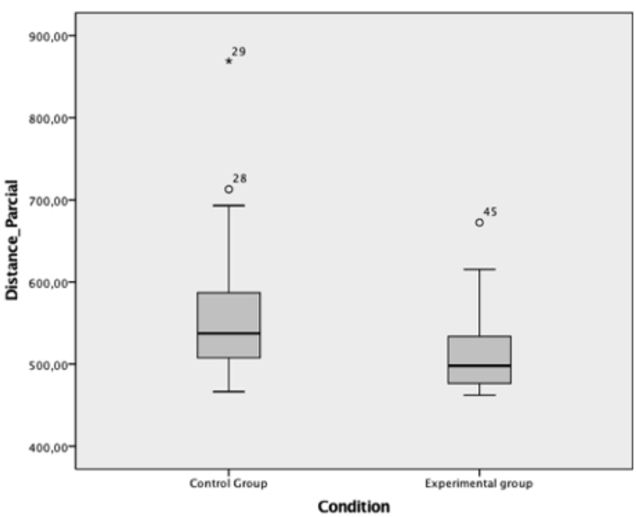

Figure 9. Boxplots for distance traveled by experimental condition.

t-test was performed to verify statistically significant differences between means from both groups. Results show that mean distance traveled in the simulation differences are statistically significant (t (56) = 2.611; $p < .05$; 95% CI [10.90, 82.76]). According to t-test results, participants in the control group walked, on average, between 10.90 m to 82.76 m more than those exposed to the technology-based emergency escape signs did.

5. Conclusion

Smart active systems have been proposed for improving safety in complex buildings. They are technology-based systems that are activated only when necessary during emergency circumstances. Nowadays, some low-cost proposals can be found, such as the use of flashing lights or wearable technology, mainly based on wireless network protocols, that have the intention of optimizing the emergency egress, directing people by the shortest safe route, like those proposed by Gorbil and Gelenbe (2011), Chung-Chou and colleagues (2013) and Kim and colleagues (2018). Efforts have been done considering the development of algorithms and electronical components, however the effects of this new paradigm with regards to peoples behavioral compliance with new technology-based emergency signs is still a concern. Few studies can be found considering new design approaches for emergency escape signs and the efficiency of those new systems has been little investigated.

In this context, data attained in this study provide insights about the importance of verifying the effectiveness of new emergency escape signs for smart buildings considering users' wayfinding behavior while interacting with a simulated emergency. The main objective of this study was to investigate the relative influence of a new paradigm for emergency egress signs, based on technology, when compared to the static emergency escape signs, in the users' wayfinding behavior during an emergency egress. A conflicting situation was considered (i.e., environmental variables and direction posted in the signs present contradictory information, for instance, in a two-way intersection, one of the available paths was brighter and wider than the other, attracting participants' to it, and an exit sign was placed pointing to the opposite direction, a darker and narrower corridor).

The main results show that a high percentage of participants in an emergency and stressful condition chose not to follow the direction posted in static emergency escape signs when the sign was available for the first time (C1). Considering that missing the right direction in the first available exit sign could, predictably, make people walk greater distances and spend more time than necessary to escape from a hazardous situation and could potentially increase the likelihood of injury or death, this result is distressing. When technology-based emergency escape signs were considered, a higher percentage of participants preferred to follow the direction indicated on the sign since its first appearance.

Participants also improved their performance considering evacuation time and distance traveled in the simulation when using technology-based signs. Considering static emergency escape signs, participants stayed, on average, between 53s and 8s more time exposed to the danger than when they interacted with the technology-based ones, and walked in average between 10.90 m to 82.76 m more than those exposed to the technology-based signs did.

Although, it was not the intention of this research to discuss the quality of the design of the signs, new design solutions and implementation of the signage system in architectural design may be considered. This allows future studies to go further into a new paradigm for active systems for emergency signage embodied in smart buildings. Future studies should also consider populated environments to verify the robustness of active smart systems, even considering social influences.

It is of great importance to understand what may influence the human behavior in a stressful situation to address the safety of occupants of a building. The prediction and anticipation of human behavior can be considered key factors for those interested in emergency events, having an impact on several levels of interventions, from architectural design, signage design, and management to fire protection engineering. According to O'Connor (2005), it is difficult to predict the responses and behaviors of people in emergency circumstances accurately. In this way, the current study allowed a step forward in this field of research, considering Virtual Reality as an interaction environment to a study design solutions considering human behavior. Data acquired in this study showed high levels of presence, even using a semi-immersive approach. Future studies may benefit from this to overcome methodological and ethical issues that are related to exposure to stressful situations.

Results from this study allow professionals and researchers in the area of safety design to have insight into new approaches for active safety systems to optimize emergency evacuation. It also strengthens the importance of the social sciences in giving a new direction to safety science, namely by incorporating actual human behavior into simulation models of emergency evacuations and improving the dialogue between architects, designers, engineers, computer scientists, fire scientists, and human factors scientists.

Despite the fact that technology-based safety signs can have a high financial cost than the current emergency exit signs, they are much more efficient, decreasing substantially the human cost in injuries or even deaths. The findings from this study lead us to re-think and review the current safety signs international standards, considering the use of technology when designing safety signs, namely for complex buildings.

Acknowledgment

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