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Usability of virtual reality for basic design education: a comparative study with paper-based design

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Abstract

Virtual reality (VR) is an emerging technology that is being used in a wide range of fields such as medicine, gaming, psychology and sociology. The use of VR is promising in the field of education and requires investigation, but research on the use of VR in education is still limited. This enables the exploration of new territories, and design education is one of them. Design education, an important part of the curriculum of architecture students who aim to conceptualize problem-solving, is still taught using traditional methodologies with touches of digital technologies. Thus, there is limited research into the implementation of VR. This study proposes using VR in basic design education and focuses on the usability of VR, especially for problem-solving activities. It presents the literature on basic design education of digital approaches, VR technologies, usability criteria and the technology acceptance model. In order to analyse the usability of VR, we conducted an experimental study with 20 first-year interior architecture and architecture students. We found that, statistically, there is a significant difference in terms of 'the intention to use' and 'the perceived enjoyment' between the VR group and the paper-based group. Moreover, there is, statistically, a difference in effectiveness within the paper-based group and the VR-based group when one compares the success of two types of design problems in the same group. Thus, one can summarize that using VR can strongly enhance problem-solving activities in interior architecture and for architecture students and that one can consider it to be a promising and complementary tool in basic design education.

Keywords Basic design education · Technology acceptance model · Usability · Virtual reality

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Introduction

In the era of technology, the use of computers and other technologies in design is inevitable. Until the 90s, design education was taught using traditional ways. However, computer-aided design (CAD) now has great value in design education. Digital methodologies enhance the precise capabilities of productive and performative processes that did not exist in previous traditional, paper-based methods. According to Oxman (2008), these technologies also change the traditional processes and layout of traditional design, and students must know the conceptual strategies of the new digital technologies; because digital techniques provide students with distinct thinking mechanisms and approaches, which allow them to express their ideas efficiently. “Traditional concepts of (paper-based) representation today lose their centrality as a conceptual basis for explicating the processes and knowledge associated with digital design” (Oxman 2008:102). Virtual Reality (VR) has huge potential in design (Portmanet al. 2015). It is simple, manageable, motivating, agreeable and pleasant for sketching in early stage design (Rieuf et al. 2017). However, in design education, there is limited research into the implementation of VR. This study focuses on the usability of VR in design education through an experimental study conducted during problem-solving activities in basic design education. It presents the basic design education literature on digital approaches, VR technologies, usability criteria and the technology acceptance model (TAM).

Background

Basic design education

In 1918, Bauhaus School of design, architecture and applied arts was established in Germany. From it came the foundation of today’s understanding of basic design learning. In order to enforce collaboration in industry and design, the Bauhaus institution initiated design education. This combined the elements of design education with fine arts. Bauhaus was the school that provided an opportunity to perform courageous experiments while using students’ imagination to consider design elements (Ozsoy 2003).

In the literature, there are various definitions of basic design education. All these definitions commonly focus on the following issues: creativity and problem-solving ability, visual perception and the visual language (Beşgen et al. 2015; Denel 1981; Kuloğlu and Asasoğlu 2010; Lang 1987; Makaklı and Özker 2015; Salama and Wilkinson 2007). The visual language is the root of design creation (Wong 1993) and is mainly based on the *elements* of form and the *laws* for putting them together (Jones 1969). Recognition of visual sophistication is the elementary aim of basic design education (Zelanski and Fisher 1996). Moreover, basic design education aims to raise awareness and provide visual sensitivity in transferring an image onto the design field (Akbulut 2010). The design field is either two-dimensional (2D) and created by points, lines and planes or three-dimensional (3D) and created by cubes, spheres, cones, cylinders and pyramids.

Basic design problem-solving requires working with the three main issues. The first issue is abstraction, which is achieved by both 2D and 3D elements and based on a system of organization, such as central, axial, radial, linear, gridal and nodal, etc. Students deal with one or more systems to create solution alternatives for ill-defined problems (Casakin and Goldschmidt 1999). Those problems guide students to learn by doing (Schon 1985) and to deal with abstract compositions rather than concrete products (Güngör 2005). The second critical issue is the characteristics of design, which are described in terms of shape, size/scale/proportion and direction/orientation. The third critical issue is the quality of design, which is defined as unity, order, harmony, hierarchy, balance and rhythm. Design students consider these issues cumulatively in the early stages of design. When one includes digital environments to the early stage of design, students are even more motivated to overcome the challenges of these three issues (Varınlıoğlu et al. 2015).

Digital technologies within the discipline of design education

As digital technologies become widely used in designing products, buildings and infrastructure, researchers have also developed a wide range of digital tools to be used within the discipline of design education. The early CAD models were created in 1980 (McCullough et al. 1990). Within the discipline of design education, there has been a gradual departure from paper-based design media since the 80s (Oxman 2017). Early CAD systems in design education were generally a representational medium for 2D and 3D modelling (Oxman and Oxman 1992). With the technological advances of design research, early models of artificial intelligence (AI) were able to design education in the form of knowledge-based design (KBD), where the cognitive processes of design thinking were developed through computational search and the formulation of generic knowledge mechanisms (Oxman 2004; Oxman and Gero 1987). In the last decade, the integration of materialization technology (including 3D fabrication and robotics) has made advances in design education; scripting or writing a code provides a new way of design thinking (Akin et al. 2018; Burry 2011; Reas and Fry 2014). The flow of information from concept to design is supported by an algorithmic mode of thinking.

The switch to digital in design education has created a significant change in information visualization techniques such as the use of VR, Augmented Reality (AR) and other game engine based mixed reality (MR) techniques (Chi et al. 2013; Dufva and Dufva 2019). VR replaces user perception of the surrounding world with a computer-generated artificial 3D environment so that a real environment is not necessary for cognitive experience to occur (Kim et al. 2013; Lanier 1992). With visual and immersive aids VR lets users experience a real sensation, whereas AR integrates images of virtual objects into the real world to create an augmented scene (Li et al. 2018). The main difference between VR and AR lies in the establishment of immersion or the mechanism of display (Hou et al. 2013). MR blends reality and virtuality, such that a VR generated virtual environment can be superimposed onto its relative real world (Li et al. 2018). In MR, the percentages of real and virtual environment can be adjusted depending on the nature of the design. In this study, we chose the VR environment to support design education goals, because VR has a huge potential in architectural design. It offers both realistic and dynamic representations along with increased visual perceptions (Akin et al. 2018). The three dimensionality of design artefacts is critical in basic design education, and VR devices with various degrees of the fidelity are achieved by mimicking human senses (vision, hearing, touch, proprioception and smell). This allows designers to mentally construct 3D models from a virtual environment, rather than from a 2D screen (Sopher et al. 2018). In this study, VR enabled users to perform a virtual walkthrough and experience a sense of presence in the dynamic display without the need of a real environment (Kim et al. 2013; Lanier 1992; Li et al. 2018). The next section elaborates on the significance of VR for architectural design in a more comprehensive manner.

Virtual reality in architectural design problem-solving

Virtual reality (VR) is defined as "the component of communication, which takes place in a computer-generated synthetic space and embeds humans as an integral part of the system…" (Portman et al. 2015). It is a world beyond reality (Berg and Vance 2016), as digital technology, which includes "3D computer graphics, real-time simulation techniques, and a wide array of input and output devices, powers interactivity, real-time rendering and self-navigation" (Erdoğan-Ford 2017).

VR has also changed the way that computers are used in processing big volumes of abstract data in architectural design. One can now experience the data with the touchable and visible features of a virtual environment (Zhi-qiang 2017). The benefits of VR in architectural design are: allowing users to visualize building models; shifting traditional 2D graphical representation towards real-time walkthrough; representing multi-dimensional design space; increasing the possibility of having multi-dimensional design spaces by adding new components or linking various application packages; and providing real-time and multi-user interactions between the designer and the building model, designer and designer or among building objects (Ding et al. 2003).

Whilst these benefits make VR technology a desirable setting for supporting the objectives and means of design education, there is a range of variables that affect the immersion of the user in the digital environment of VR (Coxon et al. 2016; Wirth et al. 2007). The sense of being spatially located within the VR environment is known as physical or spatial presence (Lee 2004). The extent to which someone experiences this sense of location within VR varies between individuals depending on their individual characteristics and the technical variables of the digital system. Since spatial presence influences how efficiently the user processes the spatial relations within the environment, it is an unavoidable fact that the VR educational setting requires a careful consideration of the relationship between spatial presence and spatial ability. Consistent with this limitation of VR, the success and user adoption of VR technologies depend on the quality of the user's experience. Although there are methods to assess user experience in VR, none of them is widely adopted (Somak et al. 2018). Moreover, user adaptation is highly related to VR sickness, in which users experience symptoms similar to classical motion sickness (Gallagher and Ferr 2018; Oman 1990). It should be noted that the consequence of VR sickness could cause users to avoid using VR in the near future (Davis et al. 2014).

Therefore, in spite of the above challenges and limitations, VR has proven to be an engaging and pleasurable medium, which has a good vector for the intention of the designer (Rieuf et al. 2017). After being immersed in a VR environment, users experience an emotional and rational perception of a realistic 3D environment; this experience can be used to develop new ideas and increase empathy in regards to spatial requirements (Ji et al. 2018). In addition, designers found the VR experience more fun, pleasing and engaging than the traditional method of pencil and paper sketching. They accepted it enthusiastically (Rahimian and Ibrahim 2011). So far, there are not many VR tools being developed or used in basic design education (Rieuf et al. 2017). VR has the potential to reduce the need for performing the redundant physical actions required for basic design education and for two- and three-dimensional sketching, modelling and organizing systems.

Technology acceptance model

As a result of studies in various fields, VR gains acceptance day by day. Reviewing the literature on VR usability, there are various types of usability studies: The post-study system usability questionnaire (PSSUQ) (Lewis 1990), software usability measurement inventory (SUMI) (Costalli et al. 2001), user experience questionnaire (UEQ) (UEQ 2018), software usability scale (SUS) (Brooke 1996), and user experience model (UX) (Norman 2004). TAM is one of the most popular frameworks in user-based evaluations (Davis et al. 1989). TAM explains user attitude towards the technology and the usage effects of that technology. It focuses on how the external features of the system affect the attitudes and perceptions that lead to the actual use of the system, based on the theory of logical action (Balog and Pribeanu 2009). TAM is able to provide an explanation of the determinants of computer acceptance that is generally capable of explaining user behaviour across a broad range of end-user computing technologies and user populations, while at the same time being theoretically justified (Davis 1989). TAM has four components: *perceived usefulness* (*PU*), *perceived ease of use* (*PEU*), *intention to use* (*IU*) and *perceived enjoyment* (*PE*).

Perceived usefulness (PU) is described as the degree to which a person believes that using a particular system would enhance his or her job performance (Davis 1989). It is based on the perception of the user and it explains how the user approaches the technology and how this technology enhances the performance and adaptation time of the user (Tenemaza et al. 2016). The level of the user's approach affects usefulness (Balog and Pribeanu 2009). When the user observes the system's positive outcomes, this will improve the user's attitudes about using the system as well as their intention to use the system (Balog and Pribeanu 2009).

Perceived ease of use (PEU) is the degree to which a person believes that using a particular system would be effortless (Davis 1989). The more the system is effortless and easy, the higher the degree of affection of the user from their perception will increase in a positive way. PEU decreases the user's physical and mental effort (Tenemaza et al. 2016). Perceived Usefulness and PEU components are influenced by diverse external variables, such as level of education (Burton-Jones and Hubona 2005), gender (Venkatesh and Morris 2000) or level of training in computer use (Venkatesh 1999).

Intention to use (IU) is defined as the level of intention that the user has to actually use the system (Moon and Kim 2001). Perceived usefulness and perceived enjoyment affect one's intention (Venkatesh et al. 2003). Intention to use indicates the real use of the system (Abu-Dalbouh et al. 2017). *Perceived enjoyment* (PE) is the extent to which one perceives using a specific system to be enjoyable in its own rights, aside from any performance consequences resulting from system use (Venkatesh 2000). Motivation is the most important factor of perceived enjoyment. When a user experiences positive outcome of the system, the system directly and positively motivates the user to use this system.

Methodology

This study was approved by the Bilkent University Institutional Ethical Review Board. All the participants were asked to sign an informed consent, which stated the purposes of the study and explained the participants' involvement as well as the risks and emergency

Fig. 1 Given design problems **a** design problems were created for an VR environment where participants ▶ solved them in it **b** design problems were created for paper-based (traditional environment) where participants solved them in it

procedures. After signing, they were enrolled in the study. They were also informed that the study was confidential and they had the right to terminate their participation at any time.

The setting and the participants

Within the framework of this experimental study, a total of 20 first-year undergraduate students from the departments of Interior Architecture and Architecture at Bilkent University were chosen voluntarily. The participants were assumed to have equivalent computer literacy skill levels of CAD systems equivalent to the standards of their high school backgrounds. They were divided into two groups: a (1) VR-based group and a (2) paper-based group. Each group had ten participants ranging in age from 18 to 21 years. The VR-based group had six female and four male participants; the paper-based group had eight female and two male participants. The first author conducted this experimental study in two settings. The VR-based group generated the experiments in the computer laboratory, whereas the paper-based group did the experiments in a real studio environment. All the participants solved the given design problems individually and each problem took approximately two and a half hours for each participant.

Figure 1 illustrates the design briefs of the given problems for the groups. Each group had two types of design problems. The reason for giving two types of problems was to test the learning effect and to control the change of variables in the design process. In the VR design problems, participants were asked to develop a 3D virtual concept model representing a flow of space. The most important feature of the design problems was that one could understand flow through an appropriate number of squares and rectangles and as well as through linear elements with different proportions. The problem definition and the specifications were the same in the two VR design problems; the only difference was the configuration of flow regarding the geometrical elements. In the paper-based problems, participants were asked to develop a real space 3D model with given boundary dimensions. The diversity of geometrical elements and the important features to be achieved were the same in the VR problems; the only difference was the specified dimensions within a specified design field.

Software and hardware

We chose Google Blocks (2018) software application for the given design problem in VR-based group. It is a Google-based application on the VR market, which can be downloaded for free. It has different commands to create regular and irregular shapes that can be moved, turned and rotated in every direction. They can also be coloured. It is easy to use commercial software, and it could be appropriate especially for basic design tasks. These characteristics of the software application made it appropriate for basic design problems. The virtual reality head-mounted display, Oculus Rift DK2 (with head-mounted glasses, two sensors and two controllers), was used for the experiments. Oculus Rift DK2 has a resolution of 960×1080 pixels per eye, a 100 field of view and a 75 Hz refresh rate. It is connected to

A Design Aspects

Qualities of design: Unity, Order, Harmony, Hierarchy, Balance,Rhythm
Characteristics of design elements: Shape, Size / Scale / Proportion, Direction / Orientation
Systems of organization: Central, Axial, Radial, Linear, Gridal, Nodal

3D MODEL OF FLOW OF SPACE

VR Design Problem 1	VR Design Problem 2
You have already worked on the notions of "variation" and "transformation" with the ultimate aim to understand how they can help you to enrich your designs. Now, you should develop a 3D virtual concept model that represents a flow of space within a design field. This flow is composed of (minimum 6 and maximum 12) squares and (minimum 3 and maximum 6) rectangles where the different proportions should be used for both squares and rectangles (2 different squares, 3 different rectangles). You could also use linear elements with same proportion of geometric shape to elaborate the relations. It is assumed that your 3D model is in the space so that the flow should be understandable from every side of your model.	You have already worked on the notions of "variation" and "transformation" with the ultimate aim to understand how they can help you to enrich your designs. Now, you should develop a 3D virtual concept model that represents a flow of space within a design field. This flow is composed of (minimum 6 and maximum 12) rectangles where the different proportions should be used for each rectangles (3 different rectangles). You could also use linear elements with same proportion of geometric shape to elaborate the relations. It is assumed that your 3D model is in the space so that the flow should be understandable from every side of your model.
Tools: Touch set Use Oculus Rift head set Google Blocks application Squares: 1 Unit, 2 Unit Rectangles: 1 Unit, 2 Unit, 3 Unit	Tools: Touch set Use Oculus Rift head set Google Blocks application Rectangles: 1 Unit, 2 Unit, 3 Unit

B Design Aspects

Qualities of design: Unity, Order, Harmony, Hierarchy, Balance, Rhythm
Characteristics of design elements: Shape, Size / Scale / Proportion, Direction / Orientation
Systems of organization: Central, Axial, Radial, Linear, Gridal, Nodal

3D MODEL OF FLOW OF SPACE

Paper-based Design Problem 1	Paper-based Design Problem 2
You have already worked on the notions of "variation" and "transformation" with the ultimate aim to understand how they can help you to enrich your designs. Now, you should develop a 3D concept model that represents a flow of space within a 20x20x20 cm design field. This flow is composed of (minimum 6 and maximum 12) squares and rectangles (minimum 3 and maximum 6 for each shape) where the lengths can be only 4, 8 or 16 centimeters (4x4 square, 4x8 rectangle, 8x8 square, 8x16 rectangle). You could also use linear elements with same dimensions to elaborate the relations. It is assumed that your 3D model is in the space so that the flow should be understandable from every side of your model.	You have already worked on the notions of "variation" and "transformation" with the ultimate aim to understand how they can help you to enrich your designs. Now, you should develop a 3D concept model that represents a flow of space within a 20x20x20 cm design field. This flow is composed of (minimum 3 and maximum 6) squares where the lengths can be only 4, 8 or 16 centimeters (4x4 square, 8x8 square, 16x16 squeare). You could also use linear elements with same dimensions to elaborate the relations. It is assumed that your 3D model is in the space so that the flow should be understandable from every side of your model.
Tools: Use your model making equipment.	Tools: Use your model making equipment.

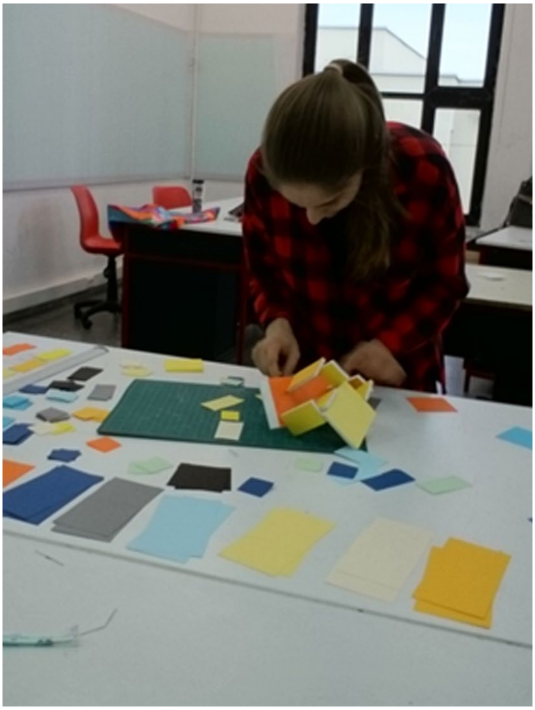
a 17inch desktop with 9th GenIntel®Core™ i9 9900 K processor and NVIDIA® GeForce® gtx 1080 TI graphic card. Figure 2 illustrates one of the VR participants wearing the head-mounted glasses with two controllers and solving the design problem within the Google Blocks software. One of the paper-based participants is presented in Fig. 3 using traditional problem-solving media and conventional craft materials such as pencil, paper, glue and cardboard.

Procedure

The experiment was composed of five consecutive phases for each group (Fig. 4). For the VR-based group, there were three main tasks in the virtual reality environment in the first phase. In the first task, participants experienced the VR tool by wearing the Oculus Rift DK2 HMDs on their head and hands. They adjusted the VR tool according to their height and they arranged the space that they were using for walking and moving

Fig. 2 An exemplary scene of a VR-based participant who was solving a design problem with Oculus Rift DK2 and Google Blocks

Fig. 3 An exemplary scene of a paper-based participant who was solving a design problem with traditional materials



their hands; they conducted a general demo trial of the tool and the Google Blocks software to learn how to use the VR tool along with the design using the software application. As a second task, participants solved the given VR design problem and saved their projects on the Google Poly (2018) website. In the third task, after they published their projects on this website, they filled out the Presence Test Questionnaire. The second phase of the VR-based group was to solve a paper-based problem in a paper-based environment. First, they read the problem; later, they started to design their project with the traditional media. They were given readymade materials (Fig. 3): square cardboard, rectangle cardboard, linear elements, coloured papers, glue and nails, blank papers, pens and erasers. After the participants solved the problem, they explained their solution by writing their descriptions on the given papers. The third phase was to solve the second VR problem with similar steps to phase 1, excluding the demo trials. The fourth and fifth phases were allocated for the TAM questionnaire, which the students conducted (the course instructors conducted an effectiveness test). For the paper-based group, the only difference was the order of the phases, based on their content and the format of the given design problems. First, participants were asked to solve the first paper-based problem by using materials such as square and rectangle cardboard, coloured papers and pens, etc. In the second phase, the procedure was totally the same with phase 1 of the VR-based group. The participants solved the first VR problem with the given tools after they finished the demo trials. They then answered the presence test questionnaire. In phase 3, participants solved their second paper-based problem, then, the same as in the VR-based group; participants answered TAM in phase 4. Finally, the experts evaluated the projects according to the Effectiveness Tests in phase 5.

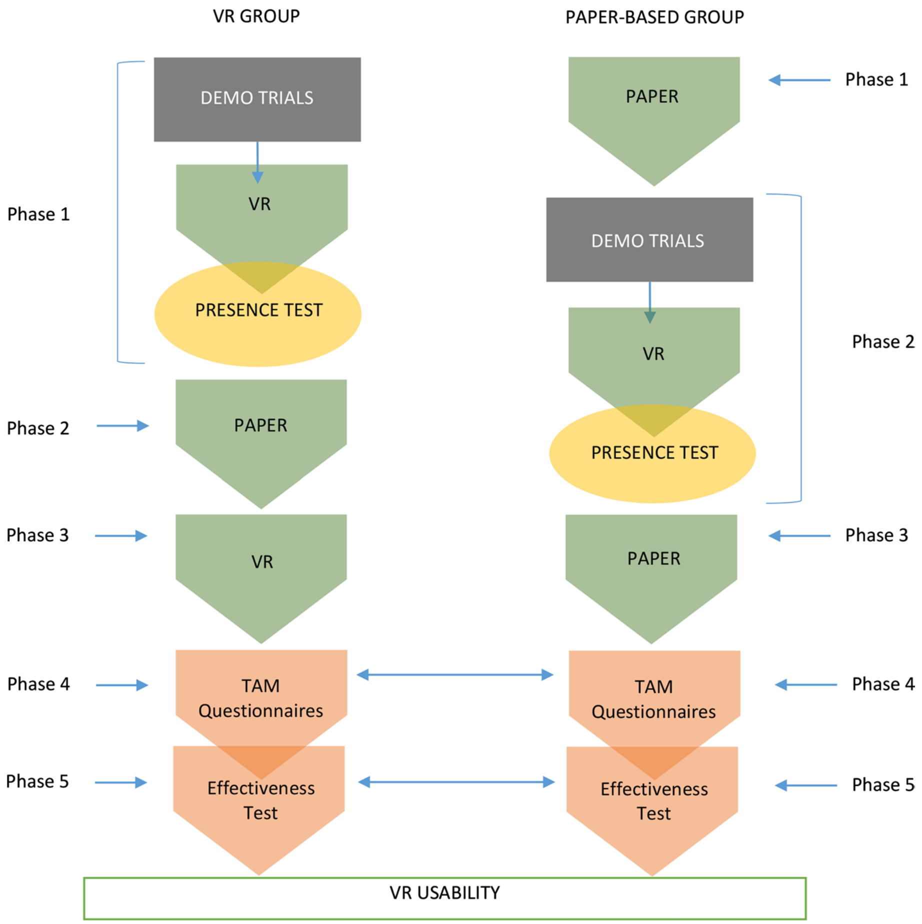


Fig. 4 Progress diagram of the experiment

Instruments

The questionnaires, which the participants completed, were the technology familiarity test (TFT), the presence test (PT) and TAM for VR and paper-based. There was also an effectiveness test, which was completed by the two course instructors in order to evaluate the success of the design solutions based on the three following criteria: (1) qualities of design based on unity, order, harmony, hierarchy, balance and rhythm; (2) characteristics of design elements based on shape, size, scale, proportion, direction and orientation; and (3) system of organization based on being central, axial, radial, linear, gridal, nodal and multi-nodal. Instructors gave a score for each item between a range of 1–10, 10 being the highest. At the end, the total scores were calculated to find the effectiveness value of the design solutions.

The TFT in the study was adapted from O'Brien et al. (2015). The participants were provided with nine statements. The statements were related to their familiarity with VR and Internet technologies in terms of time duration and usage patterns. Two example questions included: Have you ever used a virtual reality system; and how often do you use the Internet each week?

The self-rated PT that we used in this study was adapted from the study of Witmer and Singer (1998). It was composed of 32 questions to assess the experience of feeling and being in an environment. When virtual environments are considered, presence is closely related with experiencing the artificial computer-generated environment. The participants assessed the degrees of presence in the study using a 5-point Likert scale (1 for compelling and 5 for not compelling). Some example questions were as follows: How well could you manipulate the objects; How involved were you in the virtual experience; How much were you able to control events; etc.

We reviewed a large number of TAM studies extensively (Chesney 2006; Davis 1989, 1993; Davis et al. 1989; Hsu and Lu 2004; Van Raaij and Schepers 2008; Venkatesh 2000; Venkatesh et al. 2003) to develop an adapted TAM questionnaire model for VR and paper-based settings (See “Appendix A and B”). Adapted from Davis (1989), in this study TAM included a total of 20 questions divided into four categories: (1) perceived usefulness; (2) perceived ease of use; (3) intention to use; and (4) perceived enjoyment.

Results

We performed the statistical analyses using the IBM SPSS Statistics 22.0 software package for descriptive analysis, *t*-tests and correlation analysis to test the success, TAM usability and effectiveness of the groups. Only one participant was very familiar with Oculus Rift DK2 technologies, and ten participants were familiar with VR technologies as Goggles. The rest were not familiar with VR at all. According to TFT results, all of them spent more than ten hours a week using a computer and the Internet. The result of the PT showed that the participants were largely involved in VR [Mean (M) = 4.14, Standard Deviation (SD) = 0.349]. Therefore, participants felt fully immersed during the problem-solving activity in VR. Moreover, basic design course grades for each participant in the two groups were compared in order to determine whether there was statistical evidence that the group grade means were significantly different. For this purpose, independent samples t-tests were applied, and it was found that there was, statistically, an effectiveness difference within the paper-based group ($t = 12.725$, $df = 9$, $p = 0.000$) and the VR-based group ($t = 22.638$, $df = 9$, $p = 0.000$) when one compared the success of the two types of design problems in the same group.

TAM findings

Reliability tests of TAM for the VR and paper groups were conducted, and the Cronbach’s alpha value was found to be 0.89 and 0.83, respectively. These results showed that the test was highly reliable (Table 1). Table 2 and Fig. 5 illustrate the comparison of the mean values of the TAM’s four components for each group. The mean differences of the TAM components in the paper-based and VR-based groups showed that VR, as a design medium, was perceived as more enjoyable than the conventional paper media.

In order to indicate whether there was a significant difference between the pairs of TAM components within the VR- and paper-based groups separately, we conducted paired sample t-tests. According to the paired samples *t* test, there was not any statistically significant difference between PPU and VRPU ($t = -1.057$, $df = 19$, $p = 0.152$), (PPU $M = 3.2665$,

Table 1 TAM shortened titles

TAM components	Media	
	Paper	VR
Perceived usefulness PU	PPU	VPU
Perceived ease of use PEU	PPEU	VPEU
Intention to use IU	PIU	VIU
Perceived enjoyment PE	PPE	VPE

Table 2 Mean comparison between and within the groups

Categories of questions	Mean values of paper-based group	Mean values of VR-based group
Paper PU	3.17	3.37
Paper PEU	3.45	3.57
Paper IU	3.29	3.40
Paper PE	3.30	3.48
VR PU	3.60	3.50
VR PEU	3.35	3.27
VR IU	4.23	3.64
VR PE	4.66	4.74

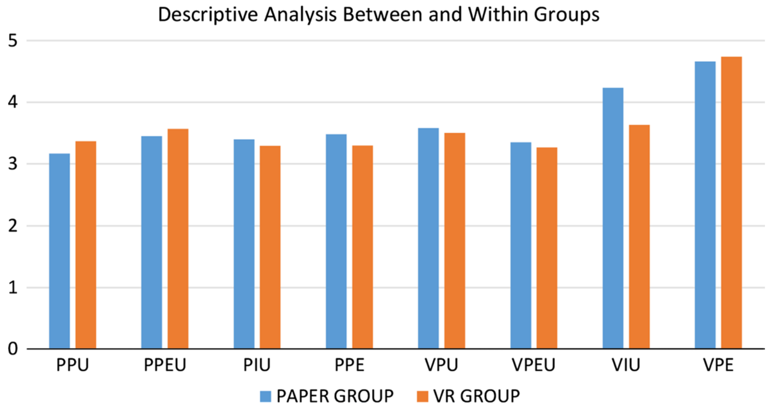


Fig. 5 Usability comparison between the VR and paper-based groups

SD = .935448, VRPU M = 3.6, SD = .76491). Therefore, one could say that there was not a statistically significant PU difference between VR- and paper-based groups. There was also not any statistically significant difference between PPEU and VPE (t = 0.923, df = 19, $p = 0.368$), (PPEU M = 3.3095, SD = .85013, VPEU M = 3.3085, SD = .57456). However, we found that there were statistically significant differences between the two following components of TAM: PIU and VIU (t = -1.820, df = 19, $p = 0.0425$), (PIU M = 3.3995, SD = .76419, VIU M = 3.8840, SD = .72757); PPE and VPE (t = −5.331, df = 19, $p = 0.000$), (PPE M = 3.39, SD = 1.05726, VPE M = 4.69, SD = .49101). Table 3 illustrates this TAM comparison analysis within the groups.

Table 3 Comparison analysis within groups in terms of four components of TAM

	t	df	*p*
PPU-VPU	– 1.057	19	0.152
PPEU-VPEU	0.923	19	0.368
PIU-VIU	– 1.820	19	**0.043**
PPE-VPE	– 5.331	19	**0.000**

p is significant at the 0·05 level

Correlation analysis

We analysed the correlations among the four components of TAMs according to the Pearson Correlation Coefficient. According to Howitt and Cramer (1999), values between -1 and 1 show the degree of relationships. For instance, a correlation point of 1.00 shows that there is a positive perfect association between variables, whereas -0.5 shows a negative moderate relationship between variables. Considering the VR group, positive medium and strong correlations were found, when PU statements were correlated with IU and PE. We found that there was a positive moderate correlation between *'I intend to use any system using VR when it becomes available in basic design courses' (q13)* and the three following statements: '*VR enables me to accomplish a task more quickly' (q1)* ($r = 0.631$ $p = 0.003$); *'VR makes it easier to do my job' (q3); 'VR has improved my productivity' (q4); and 'VR tools enhance my effectiveness on the job' (q6)* ($r = 0.590$, $p = 0.005$).

On the other hand, when we correlated PE and PU, we found that there was a strong correlation between *'VR tools enhance my effectiveness on the job' (q6)* and the following two statements: '*System is pleasant' (q17)* ($r = 0.882$, $p = 0.000$); and *'Feel enjoyment' (q18)* ($r = 0.701$, $p = 0.024$) (Table 3).

The TAM for the paper-based group was also analysed. According to the correlations among PU, PEU, IU and PE, we found that there was only one significant correlation when we correlated PU and PE. *'Paper-based tools give me greater control over my job' (q5)* was moderately correlated to '*Paper-based tools enhance my effectiveness on the job' (q6)* ($r = 0.523$, $p = 0.004$). There was also one positive strong correlation between '*Paper-based tools have improved my productivity' (q4)* and '*I am rarely frustrated when using paper-based tools' (q12)* ($r = 0.798$, $p = 0.000$).

Discussions

The statistical results of the study showed that there was not any significant difference between VR and paper-based tools in terms of usefulness and ease. However, there were significant differences in terms of enjoyment and intention to use. When all the mean values of TAM for VR and paper-based groups were compared, one could say that the participants found VR more enjoyable and had more intention to use. When the mean differences between the groups were explained in terms of the four components of TAM- PU, PEU, IU and PE, the paper-based group found that VR was more useful and had more intention to use.

The findings were in line with findings obtained from previous VR studies on (Berg and Vance 2016; Erdoğan-Ford 2017; Kim et al .2013; Lanier 1992; Li et al. 2018; Zhiqiang 2017). We extended the findings here by suggesting a VR learning model to improve cognitive thinking of basic design education, enhance visual design perception and support basic design solution development. The model also intended to overcome the existing problems in basic design education by the potential of the digital environment. In this respect, the different t-test and correlation results between the VR-based and paper-based groups can be discussed from two points of view. First is the illusory sense of being spatially located within the digital environment (Coxon et al. 2016). Although the extent to which someone experiences this can differ according to technical variables (Cummings and Bailenson 2015) and individual characteristics, in this study, imagery ability was a critical factor. The imagery ability is the extent to which a spatial situation model has been formed (Wirth et al. 2007). As Oxman said (2008), digital methodologies in design education enhanced the performative process in design solving. This could be the reason why participants found VR more intentional to use when compared to paper-based tools. In addition to Oxman's (2008) concerns, Rieuf et al. (2017) supported the idea that immersive design tools provided pleasurable and good vectoral for designers for the intentional use. Similar to Ding et al. (2003), who found that 3D virtual worlds were more effective when compared with traditional approaches, this study also found strong correlations between system effectiveness and enjoyment of VR compared to the paper-based environment. Sanchez et al. (2000) highlighted the efficiency of VR in design education with a focus on its right and applicable use. They suggested using the design of virtual reality systems as learning tools that could build virtual worlds capable of embodying the knowledge to be taught in design education. Company et al. (2009) discussed computer-aided sketching as a tool to promote innovation in the design process. Although they found paper-and-pencil sketching useful, traditional approaches lacked functionality because they were disconnected from the later stages of the computer-aided design process. Rahimian and Ibrahim (2011) found that 3D sketching was more effective when compared with pen and paper sketching. A more recent study by Paravizo and Braatz (2019) also reported the capability of VR and AR systems in design education in building high quality and interactive 3D environments for learning. However, the most often discussed challenges of VR and AR simulation systems is the extent to which the simulation technologies represent real stations and are closely linked to the design process so that they need to be validated to include knowledge of geometry creation, manipulation, and other design generation techniques rather than knowledge of virtual tools (Vuletic et al. 2018).

The second point of view could be the attractiveness of the technology. Design students might be bored with traditional media, and VR technologies may be more attractive to a younger population (Venkatesh 2000). As Çetinkaya (2011) said, students had to be more practical in their problem-solving while they were enhancing their visual thinking efficiency in the 3D vision. Sigitov et al. (2013) discussed the robustness, extensibility and reusability of the learning systems in design education, and highlighted VR systems as being more suitable for that kind of school work. Therefore, one could consider VR environments to be more practical to enhance students' visual thinking abilities to solve their problems. According to Rieuf et al.'s study (2017), industrial design students found VR more simple, practical, manageable, inviting, appealing and motivating than traditional methods when creating mood boards. If the conceptual design is performed independently of the digital technologies in a paper-based environment, the early design outputs need to be reproduced and then further developed in the digital environment (Ye et al. 2006). In design education, the reproduction or conversion of sketches into digital models is a time consuming and error-prone process. It makes them difficult to interpret algorithmically and then automate. Bower et al. (2014) emphasized that AR systems had the potential to reduce the cognitive overload of students by overlaying rich media onto the real world for viewing through web-enabled devices such as phones and tablet devices (as well as making this available to students at the exact time and place of need). In this study, basic design students found VR intentional to use, enjoyable, pleasant, easy to use and useful during the basic design problem-solving activity compared with the paper-based environment. There was also a significant relationship between perceived usefulness and intention to use, which was supported by Davis et al. (1989). The reason they found VR more enjoyable could lie in the pedagogic character of basic design education, which focused on the learning design fundamentals of 2D and 3D geometries, abstract relationships of design elements (line, shape, color, movement and volume) and the interactions of these elements with the world (Akbulut 2010; Neves and Duarte 2015; Zelanski and Fisher 1996). Dealing with the complexity and challenge of basic design with traditional tools is difficult and negatively influences students' enjoyment of learning (Neves and Duarte 2015). In this respect, in line with the above literature, in this study, VR reduced the cognitive load of working with basic design objectives in the real world and increases students' engagement with the problem space in a responsive way, while making the learning process easy, concrete and enjoyable in the virtual world.

Balog and Pribeanu (2009) stated that perceived ease of use had a positive effect on intention to use. They supported the idea that if users felt free while using a system, and if the system itself felt effortless, they would have positive intention to use this system. However, in this study, we found that there was not any significant relationship between perceived ease of use and intention to use. The reason for this could be explained with reference to Schon's (1985) statement of 'learning by doing'. Although Heydarian et al. (2015) found that immersive virtual environments provided people with more realistic learning environments, when one considered 'learning by doing' (which played a key role in basic design education), experiences with traditional methods could be more supportive for 'learning by doing' activities.

Conclusion

This study focused on the usability of VR in design education, especially during problem-solving activities in basic design education. It presented the basic design education literature on digital approaches, virtual reality technologies, usability criteria and as well as the TAM. In order to analyse the usability of VR in basic design education, we conducted an experimental study. To summarize the experimental findings, we found that there was a statistically significant difference in terms of intention to use and perceived enjoyment between the VR group and the paper-based group. Participants in both groups found VR more enjoyable. Moreover, there was a statistically effectiveness difference within the paper-based group and the VR-based group when one compared the success of the two types of design problems in the same group. Thus, VR could strongly enhance the problem-solving activities of interior architecture and architecture students and one could consider it to be a promising and complementary tool in basic design education.

This study was an initial attempt to analyse and assess the usability of VR in the problem-solving process of basic design. Our findings provided significant basis for the literature in terms of presenting that interaction in a VR environment could be the easiest interaction type, and the participants were eager to use VR environments instead of traditional environments. The challenge lay in exploring new ways of design learning in the virtual world. In this framework, this study also added an important contribution to the design learning field by presenting how influential the digital technologies were, and the need to improve the traditional design learning tools to affect learner performance. For further studies, and to generalize the findings for various architectural design problems at a broader theoretical and practical level, one would need to track participants' head and eye movement patterns as well. Both the illusory sense of being spatially located within the digital environment (Coxon et al. 2016) and the experienced data in the VR environment with the touchable and visible features of a virtual environment (Zhi-qiang 2017) requires the need to explore cognitive behaviours of designers. Moreover, a virtual walkthrough and virtual experience of presence in the dynamic display without the need of a real environment (Kim et al. 2013; Li et al. 2018) can also influence the creativity of designers and students' creative learning process. Thus, creativity could be an additional variable for future research and the cognitive behaviours of design students could be explored based on diverse design tasks. Most of the creativity studies explore factors and measures that enhance creativity during the design learning process (Casakin 2007; Dorst and Cross 2001), accordingly, the VR learning environment could give a wide range of possibilities to study more in-depth the features of interactivity, as well as components of creativity in digital environments. As stated by Akin et al. (2018), the realistic and dynamic representations along increased visual perceptions in a VR environment could be different for various scales. Therefore, one could also investigate the relationship between imagery ability and spatial presence in different contexts, such as product design context, urban design context.

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Appendix A: Adapted TAM questionnaire model for paper-based settings

Please place an "X" in the appropriate box to rate the following items using scale of 1–5:
1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Perceived Usefulness	**1**	**2**	**3**	**4**	**5**
Paper-based tools enables me to accomplish task more quickly					
Paper-based tools has improved my quality of work					
Paper-based tools makes it easier to do my job					
Paper-based tools have improved my productivity					
Paper-based tools gives me greater control over my job					
Paper-based tools enhance my effectiveness on the job					
Perceived Ease of Use					
My interaction with the paper-based tools has been clear and understandable					
Overall, the paper-based tools are easy to use					
Learning to operate the paper-based tools were easy for me					
I rarely become confused when I use the paper-based tools					
I rarely make errors when using the paper-based tools					
I am rarely frustrated when using the paper-based tools					

Perceived Usefulness	1	2	3	4	5
Intention to Use					
I intend to use any system using paper-based environment when it becomes available in basic design					
Assuming I had access to the paper-based environment, I intend to use it					
I predict that I would use paper-based environment frequently					
Perceived Enjoyment					
System is fun to use					
System is pleasant					
Feel enjoyment					
I would like to repeat same experience					
It was interesting experience					

Appendix B: Adapted TAM questionnaire model for VR

Please place an "X" in the appropriate box to rate the following items using scale of 1–5:

1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

Perceived Usefulness	1	2	3	4	5
Virtual reality enables me to accomplish task more quickly					
Virtual reality has improved my quality of work					
Virtual reality makes it easier to do my job					
Virtual reality has improved my productivity					
Virtual reality gives me greater control over my job					
Virtual reality enhances my effectiveness on the job					
Perceived Ease of Use					
My interaction with the virtual reality has been clear and understandable					
Overall, the virtual reality is easy to use					
Learning to operate the virtual reality was easy for me					
I rarely become confused when I use the virtual reality					
I rarely make errors when using the virtual reality					
I am rarely frustrated when using the virtual reality					
Intention to Use					
I intend to use any system using virtual reality when it becomes available in basic design courses					
Assuming I had access to the virtual reality system, I intend to use it					
I predict that I would use virtual reality frequently					
Perceived Enjoyment					
System is fun to use					
System is pleasant					
Feel enjoyment					
I would like to repeat same experience					
It was interesting experience					

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