On the design of architectural spatial experiences using immersive simulation

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Abstract The paper describes current research efforts seeking to assess the potential use of immersive simulation through virtual reality (VR) environments as a tool for aiding the design of architectural spatial experiences. The design of spatial experiences demands the use of representations that handle time in addition to the other three dimensions. Tools that help us to represent design through time are the right tools for simulating and testing the satisfaction of architectural spatial experiences. Immersive VR environments are superior tools for the representation of spatial experiences if compared with conventional 3D visualization methods using renderings and/or animations. Immersive VR environments that make use of head mounted displays (HMD's) and control tools for navigation in the environment reach a higher sense of presence if compared with visualization tools using large screens or even multi-wall caves. By making use of a fully implemented VR HMD-based environment in our College of Architecture and Planning (CAP) at Ball State University, we have conducted a controlled experiment with novice architectural design students who were assigned the task of redesigning the public waiting areas of a local medical clinic. After the evaluation of results of the experiment we have found evidence of the positive impact in aiding the design of architectural spatial experiences and evidence in providing just-in-time feedback to accommodate changes in the conceptual design of the spaces. We hope that this study will promote further investigation in the use of immersive VR tools addressing intermediate levels of visualization for fast exploration of spaces and real time manipulation of objects in the environment.

Fig. 1 Immersive Simulation through VR Environments

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The main objective of this research is to understand and harness the potential use of immersive VR environments for the design of architectural spatial experiences. In particular our target is to address its application in teaching/learning situations like those implemented in design studios. Although many applications of diverse VR systems have been already implemented in several disciplines, like military training (Karr et al, 1997), training of surgical skills (Ota et al, 1995), games (Cook, 1992), and architecture (Donath & Regenbrecht, 1999; Knight et al, 2003; Hemmerling, 2008) we are using and adapting VR tools and methods for design education, at a time when these systems have become more affordable and substantially easier to use. Because of their cost and technical complexity, the use of immersive VR environments has been largely limited to the presentation of the finalized architectural artifacts; and it is seldom used as a tool in the design process in either practice or academia, which is the focus of this investigation.

Architectural Spatial Experiences

Early in my architectural education I was confronted with the awareness that one of the most difficult things we do in architecture is to project ourselves as a presence in space. I remember that our instructor first asked us to look at a building from the outside and produce several sketches. Following that initial exercise the following step was to produce additional sketches but without looking at the building. I remember going back in my memory searching for a mental image of the building and then I performed an imaginary close-up that I could draw. The third step was to imagine an extension to the building and to draw it. By then I remember thinking that I had figured out the objective of the exercise: first to see, second to remember, and third to imagine. To my surprise there was a fourth part to the exercise. That last component was to imagine the main space of the building we had been sketching from the outside and to draw it. Suddenly I realized that the objective of architecture is not the architectural artifact but the experience it facilitates, namely; the architectural experience

We can assume that design is an iterative process composed of planning, analysis and synthesis where the representations of problems and solutions, at different levels of granularity, are generated and evaluated to keep the design cycles moving and the design developing (Angulo, 1995). The experienced designer will implement a shorter design process and will choose more effective design representations to visualize the problem at hand. For instance many different representations of standardized solutions of the environmental performance of buildings guide the design of high performance buildings. Parametric methods are deployed to solve not only the environmental performance but also to design the appearance of buildings. Similarly functional arrangements, efficient circulation and cost may determine entirely the design of common interior spaces. These tendencies are challenged when designing signature spaces. These spaces include lobbies, waiting halls, and public areas that can be described as destinations in the experience of the users, and are responsible for conveying meaningful information and expressing the character of the institutions they host. An architectural spatial experience can be regarded as the egocentric perception of the individual and his/her interpretation of the phenomenological characteristics of the space. This experience is mainly visual but not restricted to the visual realm. We have realized that our conventional communication tools are only up to certain extent suitable for the design of architectural experiences of signature spaces. The design of spatial experiences demands not only the simulation of elapsed timed in addition to other 3 dimensions, but also calls for the ability to freely navigate through the designed space (Schubert et al, 2000; Biocca & Delaney, 1995; Kalisperis et al, 2006). The availability of high resolution immersive VR environments can provide full scale perception of spaces and accuracy in the representation of materiality. Immersive VR environments that make use of head mounted displays (HMD's) and control tools for navigation in the environment reach a higher sense of presence if compared with visualization tools using large screens or even multi-wall caves (Bakker, 2001). In such environments designers can simulate architectural experiences and obtain real-time sensorial perception of spaces.

Immersive CAP VR Environment

We have recently deployed VR technology in a laboratory commonly addressed as the CAP VR Environment that allows a single user to navigate three dimensional models of infinite size, while physically limited to walking around a 30x30 foot setting. The CAP VR Environment (Fig. 2) consists of a head mounted display and a tracking system that knows the exact position of the user in the real space and maps it in the 3d model. Additionally, an orientation-tracking device (gyroscope) keeps also record of the orientation/direction of the user's head. The wide-field-of-view HMD features two distinctive images for each eye creating a stereoscopic projection with 76H x 64V degrees FOV. Users do not notice any disruption/adjustment of the imaging flow when moving around the environment. A wireless 6DOF tracked hand-held wand helps the user to move around the environment at different speeds and in any direction, among other functions. Additionally in order to share the experience with others we have connected the VR system to a large screen with rear projection. The CAP VR Environment feels very immersive; the level of presence that the users experience tends to be very high due to the characteristics of the system, and the quality of the models that are used. These models contain photorealistic images, lights and shadows, and when including animated avatars, they also increase the sense of presence in the virtual space and therefore they increase the immersion. We have used the CAP VR Environment for recreating several projects, such as the visualization of our main atrium and the visualization of two versions of our school entry to the Solar Decathlon 2013 competition (CAP VR Environment, 2013). By implementing this research, we have used the environment for the first time to visualize design studio projects; moreover the students have undertaken several design iterations based on the feedback received from their navigation within the system.

Fig.2 CAP VR Environment

The Experiment

The working hypothesis that guides our research is that immersive VR environments can effectively support the process of designing architectural spatial experiences and their perception through architectural artifacts of higher quality than those spaces designed making use of traditional and/or more commonly used representational methods. For this purpose we have conducted an experiment with sophomore architectural design students who were assigned the task of redesigning the signature space of a local medical clinic. As the Fig. 3 shows in the research methodology chart, a class of 15 students was divided into two groups: the control group and the experimental group. The control group consisted of 3 teams of students and the experimental group consisted of 4 teams of students. The designation of groups and teams was done by the students who were guided by their preference in the use of media. Once the design stage was finalized the students presented their projects during a conventional project review. Additionally, the projects were reviewed by a blind panel of jurors who by doing so provided data for the research. This data was then analyzed to determine the results of the experiment. The entire research process lasted 6 weeks from the start of the project until the data was collected from the jury for further analysis.

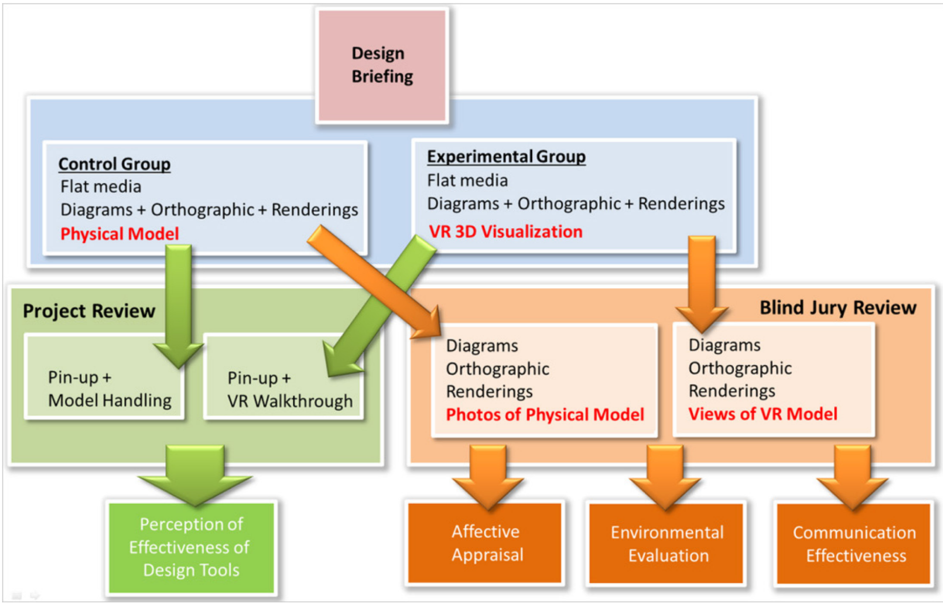

Fig. 3 Research Methodology

<u>Design briefing:</u> The experiment began by providing a design briefing. The signature space of this project was a waiting room for a local health clinic that the students visited during a field trip. The space of the waiting room in the clinic is constrained to a specific inner location in the second floor of the health clinic, with no other source of day light than the foyer at the east side of the building (Fig. 4).

Fig. 4 The physical clinic (left) and the VR clinic (right)

Given the design problem, the students researched the effects of environmental conditions in waiting rooms (Evans & McCoy, 1998) and followed specialized recommendations to alleviate stress and foster well-being among the patients (Leibrock & Harris, 2011). They were given a 3D digital model of the area for renovation. They also used the CAP VR Environment to walk around a simplified VR version of the clinic that depicted the current waiting room without any furniture, and minimum reference to colors or textures in surfaces (see Fig. 4).

Design process: The design process for both research groups progressed as in any other project through iterations of sketching and modeling. The control group used physical models at different stages of completion for design speculation but mostly for presentation purposes. They also utilized a 3D digital model provided at the beginning of the assignment to implement the design and create the final renderings. Some renderings were photorealistic and only produced for the review presentation. The experimental group on the other hand also utilized the original 3D model to introduce modifications to the geometry as needed as well as incorporating furniture elements. Additionally, they received specific training on how to make their conventional 3d digital models compatible for VR visualization. These included the assignment of standard materials to objects, addition of day light systems and artificial lights, and baking of materials and textures. All the relevant geometries were then exported to the Vizard (WorldViz, 2013) application for final display. In the majority of the cases, the teams of the experimental group implemented the entire process -from modeling to exporting to visualization- several times before obtaining the desired quality (light incidence, color adjustment, simplification of the complex objects, rationalization of number of objects, etc.) The Fig. 5 shows some views taken from the VR modeling environment of the four different projects in the experimental group.

Fig. 5 VR simulation projects

Testing: After the design was completed the students were asked to communicate their design solutions in preparation for the reviews by producing identical type of flat media. The control group prepared final physical models for presentation and the experimental group was ready with the VR models to be displayed in the CAP VR Environment. There were two reviews: (1) a conventional project review conducted by one guest reviewer and all the classmates, and (2) a blind jury review (consisted of 4 reviewers). The conventional project review was undertaken in two settings. First in a conventional classroom setting for the teams belonging to the control group. Second, the project review continued in the setting of the CAP VR Environment so the teams in the experimental group could demonstrate their virtual projects using the VR system. In both cases pin-up of boards were also used. The blind panel of jurors did not meet with each other to evaluate the projects. They did it individually with information uploaded to the web and filling out paper forms. The information of each project consisted of diagrams, orthographic drawings, renderings, and either pictures of physical models or views from the VR models depending on the type of group they belong to. The jury did not know the identity of the projects' designers. They did not use the CAP VR Environment for any walkthrough nor viewed the VR projects in the large projected screen. The jury filled out two forms for each project: a questionnaire on affective appraisal of the space, and a questionnaire on environmental evaluation of the space. Each form followed a Likert scale format that allowed us to rank the projects and compare them.

Data Collection: The best project according to the research hypothesis should be associated (1) to more positive affective appraisals of the waiting area, and (2) to more positive evaluations of environmental features if compared with other designs.

Affective Appraisal of the waiting area has been used as a tool to evaluate the space from a subjective point of view. It can be regarded as an individual's rating of a setting on a series of adjectives highly saturated in affective but with little or no reference to objective, perceptible properties of the place described (Leather et al, 1993). The questionnaire listed 11 items as a set of bipolar adjectives (i.e. open/close, relaxed/tense, pleasant/unpleasant, etc.). The jurors should choose one of two adjectives and specify their level of agreement in a Likert scale format. The 12th item in the list was filled out with commentaries but not included in the analysis. The Environmental Evaluation of the waiting area was implemented through a form that listed 14 specific items related to specific and identifiable features within the environment, for example effectiveness of the circulation, adequate furniture layout, sense of nature, etc. The criteria for evaluation listed in the forms were determined in collaboration with the students and discussed until a consensus was reached; the students proceeded to design according with these criteria that became their projects' working objectives.

Data Analysis and Results: In the affective appraisal of the spaces only the positive adjectives and their scores were used for tabulation to determining the likability of the space. If tabulating the scores on agreement and strongly agreement for each project and comparing them among each other, the Group 1 (VR –Virtual Reality team) obtains the highest score by far, followed by the Group 6 (PM -Physical Model team), Group 5 (PM), Group 4 (VR), and Group 2 (VR) with far less score difference among them. (Fig. 6).

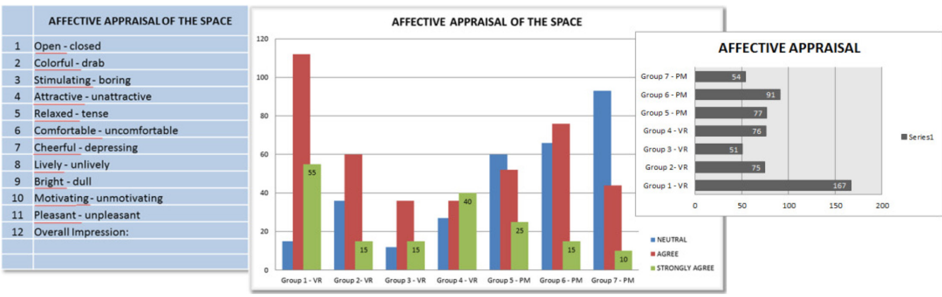

Fig. 6 Affective Appraisal: questionnaire (left) results (center and right)

In terms of the environmental evaluation, the blind jury determined again that the Group 1 (VR team) obtained the highest score (Fig. 7). In contrast with the affective appraisal, further analysis of the environmental evaluation shows that the two highest scores are achieved by teams of the experimental group (VR) at the same time that the two lowest scores are attributed to teams in the control group (PM).

	ENVIRONMENTAL EVALUATION OF THE SPACE
1	Good Depth, Scale, Height, Density
2	Efficient Circulation
3	Good Furniture Layout
4	Effective Wayfinding
5	Material Textures and Colors of Interior Surfaces
6	Effective Illumination
7	Effective Daylighting availability and control (no glare)
8	Ability to view (sense) nature
9	Sense of Privacy
10	Opportunity of Human Interaction
11	Sense of Familiarity
12	Sense of Choice or Control (incl. access to info.)
13	Positive Distraction
14	HVAC inconspicuous availability

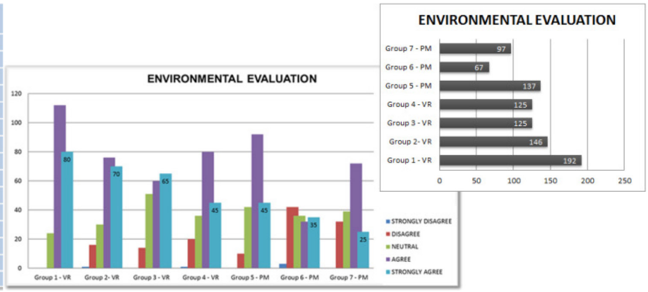

Fig. 7 Environmental Evaluation: questionnaire (left) results (right)

It is worth mentioning that the highest scored project (Group1-VR) exhibits a two-way positive correlation in affective appraisal and environmental evaluation.

Lastly, when the effective appraisal and the environmental evaluation scores are combined as expression of experiential quality, we find that the experiential group scores higher [58%] than the control group [42%] and the two best projects remain to be in the experimental group at the same time that the two less successful projects reside in the control group.

Beyond the analysis of data extracted from the blind review of projects, it is important to note that during the conventional review of projects by a guest reviewer and peers, a number of substantial differences were observed; namely:

- The reviewer and the students spent more time reviewing the projects of the experimental group. The immersive visualization of the projects attracted a higher level of interest.
- The actual level of participation of the general audience was higher when reviewing the experimental group. Students are generally shy to offer their opinions on projects, but in this case all the students in the class volunteered opinions,
- The interventions were mostly done through opinions and comments directed to improve the spaces they were looking at through the large rear projection screen. The number of clarification questions was substantially lower. The students in the audience frequently guided the HMD user to walk/navigate in specific directions to inspect interesting aspects of the proposed renovations.

Conclusions and future work

We have obtained evidence that suggests that the projects using the CAP VR environment can effectively support the design of architectural spatial experiences as measured by the blind jury panel. We have also observed that the use of VR immersive environments may expand the role of studio reviews to become more participatory and collaborative. VR immersive environments may provide in-time feedback for improvement of spatial design, and may enhance the understanding of architectural experiences of space leading to meaningful results.

We hope that this study will promote further investigation in the use of the immersive VR tools. Even though the CAP VR Environment provides a high sense of presence we don't use it more frequently in design studio because in order to create a realistic digital environment, the students must invest a larger amount of time and effort if compared with the use of other conventional digital methods. We will investigate how to implement intermediate levels of visualization for fast explorations of spaces. Progressive spatial simulation can be based on:

- the manipulation of the geometrical characteristics of the space-defining elements (shape, depth, rhythm, scale, proportion, etc.),
- the incremental application of shading, textures, and light –from basic to photorealistic, and lastly through,

- the real-time manipulation of objects in the virtual environment. Beyond being able to move some items in the space, ready-made alternative solutions can provide direct feedback from cause and effect in the virtual environment.

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