

## Rediscovering Virtual Reality in the Education of Architectural Design: The immersive simulation of spatial experiences

*Redécouvrir la réalité virtuelle dans l'enseignement de la conception architecturale: la simulation immersive des expériences spatiales*

**Antonieta Angulo**

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# Rediscovering Virtual Reality in the Education of Architectural Design: The immersive simulation of spatial experiences

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## Background

- 1 Throughout the years many applications of VR systems have been used in several disciplines - military training (Karr, *et al.*, 1997), training of surgical skills (Ota, *et al.*, 1995), games (Cook, 1992), and entertainment<sup>1</sup>, but seldom in architectural design (Donath & Regenbrecht, 1999; Knight *et al.*, 2003; Hemmerling, 2008). It is our commitment to adopt and to adapt relevant VR tools and create methods applicable in 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; it is seldom used as a tool in the design process in either practice or academia. The availability of high resolution immersive VR environments can provide full scale perception of spaces and accuracy in the representation of materiality. An immersive VR solution that makes use of an HMD (Head Mounted Display) and control tools for navigation in the environment may provide a higher sense of presence when compared with visualization tools using desktop large screens and even projection-based screen systems. By incorporating an immersive VR environment as a regular tool for the teaching of undergraduate and graduate architectural design studios, we have used the environment to visualize design projects and to receive feedback from their navigation



within the system. Immersive VR tools that support the design of enhanced architectural spaces should result in enhanced real built projects.

## Designing Architectural Spatial Experiences

- 2 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 ideal standardized solutions of the environmental performance of the building are used to design high performance buildings. Additionally, pragmatic parametric methods are currently deployed to solve not only the environmental performance but also to design the appearance and appeal of buildings. Similarly functional arrangements, efficient circulation, and cost may largely determine the design of common interior spaces. It is only when signature spaces are considered that most designers contemplate the architectural experience as a priority. Hospital lobbies, museum halls, airport waiting areas, are examples of what we call “signature spaces.” Many examples are available that show the consistency of this kind of interior space with the overall building architecture. The signature spaces convey meaningful information about their institutions. They can even express the character for which the building is going to be known for.
- 3 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. The description of architectural spatial experiences should transcend the description of the space defining objects. The aim of the design is to describe the space as a set of physical and material performances but also offer the possibility of eliciting meaning. The architectural space must evoke a series of subjective emotions that would eventually lead the user of the space to regard it as a place, and thus it potentially becomes a meaningful space. The architectural spatial experience is mainly visual but not restricted to the visual realm. We have realized that our conventional communication tools are only up to a certain extent suitable for the design of architectural experiences of signature spaces. The design of spatial experiences demands not only the simulation of elapsed time in addition to the other three dimensions, but also calls for the ability to freely navigate through the designed space (Regenbrecht & Schubert, 2002; Biocca & Delaney, 1995; Kalisperis, *et al.*, 2006). Superseding the use of ready-made animations or videos for post-design visualization of a project, VR offers an alternative for real-time sensorial perception of spaces.
- 4 VR systems range in the level of immersion they provide. Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences (Witmer & Singer, 1998). It is quite well accepted that (physical) immersion or the psychological state achieved by physical immersion contributes positively to the creation of presence. Thus, the immersion effectiveness of a VR system depends on the level of presence that a person perceives using the system. Today virtual environments (VEs) based on desktop displays and immersive projection systems are popular formats in academia, research, and industry (Cruz-Neira, 2005). Notable examples of immersive



projection-based systems include the Fish Tank VR, and multi-wall CAVE systems that are used for a variety of purposes. HMDs have been also used as a means to display immersive VEs for the last four decades (Sutherland, 1968). Research related to HMDs has generally concentrated on improving the resolution and the optics, and minimizing negative effects such as cybersickness (nausea). The actual HMD technology is highly immersive due to high environment and interface fidelity. Studies in the field state that environment fidelity reflects the quality of the sensory information provided to the user by the simulator, while interface fidelity relates to one's actions used to generate this information (Waller *et al.*, 1998).

- 5 We have chosen to make use of state-of-the-art HMD technology for the visualization of VEs simulating design studio projects in the design of architectural spatial experiences. This technology has offered us a fine alternative for visualization of a virtual environment from a first-person point of view and the ability to naturally walk and move around it.

## The CAP VR Environment

- 6 The VR technology currently in the College of Architecture and Planning (CAP) at Ball State University was initially deployed in late 2011. The Simulation Laboratory (SimLab) in CAP hosts a facility commonly addressed as the CAP VR Environment; this VE allows a single user to navigate three dimensional models of infinite size, while physically limited to walking around a room of about 6 x 6 meters (20' x 20'). The CAP VR Environment consists of a head mounted display and a tracking system that identifies the exact position of the user in the real space and maps it in the 3D model. Additionally, an orientation-tracking device (gyroscope) keeps congruent record of the orientation/direction of the user's head. The wide-field-of-view HMD features one distinctive image for each eye creating a stereoscopic display covering 102° horizontal by 64° vertical, with 111° across diagonal. Adequate eye relief accommodates users with eyeglasses and a large exit pupil supports eye movement across the expansive field-of-view without vignetting. The HMD weights about 1.3 kg which is substantially lighter than earlier versions of the same technology<sup>2</sup> (NVIS, 2014). . Users do not notice any disruption/adjustment of the imaging flow when moving around the environment. Even though the HMD is tethered to the system with a cable of about 4 meters, it remains non-intrusive because the walkthrough episodes are always aided by an assistant who facilitates the navigation. A wireless 6 degrees of freedom (DOF) tracked hand-held wand, with joystick and buttons helps the user to move around the environment at different speeds and in any direction, even flying. The students need only to point and click towards the direction they want to fly. Additionally, in order to share the experience with others we have connected the VR system to a large screen with rear stereoscopic projection. This is especially important when showing the projects during a design review, or while working in design teams allowing the collaboration and participation of others during the experience. The walkthrough experience is therefore not an isolated experience but a participatory one. Since its implementation, we have been able to recreate several academic projects, in addition to the visualization of our main atrium and two versions of our school's entry to the Solar Decathlon 2013 Competition<sup>3</sup>. Students learn to create VEs by generating the geometries of their projects using conventional 3D modeling applications. The best rendering standard is achieved following a straightforward process: the models are



assigned standard materials and the scene becomes realistic when adding daylight systems and/or artificial lights; these materials and lights are baked into the models and exported to Vizard. Vizard<sup>4</sup> is a python-based application that allows, among many other functions, for the addition of avatars, animated backgrounds, and also adjustments for the seamless playback of the VE in our immersive environment. See illustration 1.

**Illustration 1: The CAP VR Environment**



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- 7 The CAP VR Environment provides effective immersion; the level of presence that the users experience tends to be very high mainly because the navigation episodes are for the most part free of any cyber-sickness. The navigation episodes may last between 3 to 7 minutes at the most when visiting the design projects. On the other hand the environment can recreate very high quality models and allows for intuitive navigation that may also positively influence the effective immersion. When using photorealistic images, lights, shadows, and animated avatars the CAP VR Environment displays very high environmental fidelity. The CAP VR Environment also displays high interface fidelity allowing self-directed navigation and provides an efficient way to perceive virtual space, providing the users support for way finding, path integration, spatial search, distance perception and orientation among other navigational tasks (Lathrop & Kaiser, 2005). You may see a movie of the immersive experience using the CAP VR Environment following this link: [http://capvr.iweb.bsu.edu/videos/compressed/CAP\\_VR\\_Environment.mov](http://capvr.iweb.bsu.edu/videos/compressed/CAP_VR_Environment.mov)
- 8 The CAP VR Environment should aim to support the actual architectural design process, therefore aiding the process of learning how to design, rather than limiting its use as a visualization tool for finalized projects. During the development of a design the representations of the architectural space and related objects are in constant evolution. The fidelity of the representation that the user (designer) must perceive during the simulation should be consistent with its effective design stage. Therefore it is expected to lack the detail aimed for a finalized project. Only at the last stage of the design process when all spatial elements have been integrated into the project, we expect to reach a high level of environment fidelity more or less comparable with the envisioned real built environment.
- 9 Research in the field states that navigation often involves acquisition of idiothetic information in addition to visual imagery (Foo *et al.*, 2005; Campos *et al.*, 2010; Tcheang 2010). Idiothetic information is internally generated efferent and afferent signals related



to changes in vestibular<sup>5</sup> and proprioceptive<sup>6</sup> states (Riecke, *et al.*, 2002). In the CAP VR Environment the use of the HMD permits the movement of the head in any direction acquiring valuable spatial information of the VE. Some idiothetic information is also gathered by the system when it allows the user to walk in the available space. Translation to places in large VEs is achieved through the hand-held wand that permits not only walking by flying around the virtual space. The HMD interface alone provides a high degree of interface fidelity for users able to walk and move around exploring small VEs as it has been already researched in the field. The advantages of combining the HMD and the wand for the navigation of large VEs have not been ratified with research elsewhere. Nevertheless, we have observed that after a short period of learning the combined interface it allows the users to freely explore large VEs, especially by flying. It is important to notice that when navigating through the CAP VR Environment the users rely not only on vision but also on the memory of the 3D and 2D representations of the same spaces as they were created in conventional CAD tools.

## Impact of the CAP VR Environment in Architectural Design Education

- 10 We have undertaken several studies in 2013 involving undergraduate and graduate students with the aim of developing methodologies for effectively using the immersive VR environment in architectural design studios. An initial study (Angulo, 2013; Angulo & Vásquez de Velasco, 2013) was implemented in the spring semester of 2013. The study included the implementation of a controlled experiment with novice architectural design students who were assigned the task of redesigning the public waiting areas of a local medical clinic, regarded as the signature space of that building. The working hypothesis that guided this study was 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. The students' VEs were displayed in the CAP VR Environment as part of the design process. See illustration 2.



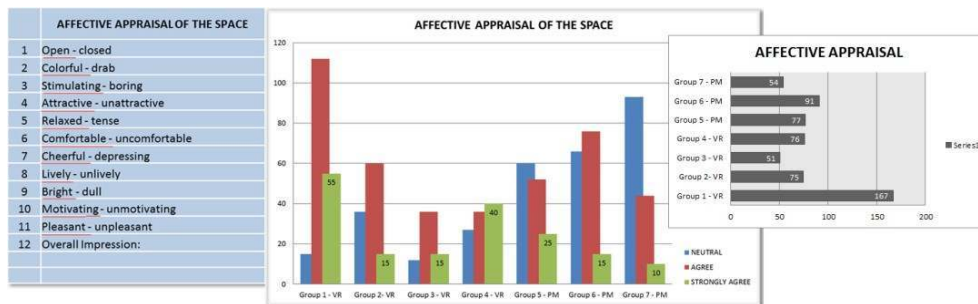
Illustration 2: VR simulation projects of the medical clinic redesign



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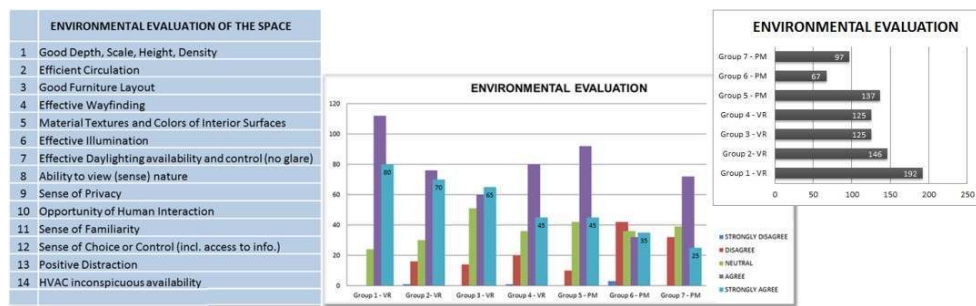
- 11 The best project according with the study's protocols was associated to (1) more positive affective appraisals of the waiting area, (2) more positive evaluations of environmental features compared with other designs, and (3) more positive evaluations regarding the use of representations for communication. After the evaluation of the results of the experiment we obtained a clear indication that the design projects using the VR system were the best projects in the class. See illustrations 3a and 3b.

Illustration 3a: Affective Appraisal: questionnaire (left) and results (center and right)



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**Illustration 3b: Environmental Evaluation: questionnaire (left) and results (right)**

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- 12 Through that initial study we concluded that the CAP VR Environment may have contributed with in-time feedback to promote/inform changes in the conceptual design of the spaces, and moreover the visualization of projects using the immersive environment may have had a positive impact on re-invigorating the participatory dynamics of the studio review<sup>7</sup>.
- 13 Encouraged by these initial findings, we have implemented a second study in the fall semester of 2013 aimed to understanding the learning benefits of using the CAP VR Environment within the design studio. The research's working hypothesis was that the students will achieve the expected learning outcome and they will have a satisfying learning experience as they simulate their designs using the CAP VR Environment. In practical terms, the immersive simulation of an actual design project would recreate the architectural characteristics of the space and would elicit an appraisal of their architectural spatial experience. The expected learning outcome of the studio, as stated by its rubric was to demonstrate the ability of the student to identify/manipulate key spatial aspects that promote the design of architectural spatial experiences. Accordingly the learning objectives that were implemented to support this effort addressed two issues: (1) to understand the performance of the space in affective and environmental terms and (2) to use adequate tools to simulate space and space-defining objects and in such a way facilitate architectural decision making. A by-product of this study consisted of the students' understanding of what spatial aspects can be suitable for simulation in the VR environment and could benefit the most from the unique sense of immersion and presence that is provided. This study made use of the rubric of expected learning outcomes stated for that particular studio in the curricula as benchmark for the assessment. No control group was used in order to safeguard a non-intrusive learning environment. The standard rubric of learning outcomes as established by our curriculum is the product of many years of instructional implementations at that particular level in the design studio sequence and therefore provides a very strong benchmark for assessment. The level of satisfaction of the students with the instrumentation of the learning experience is subsequently a product of their structured testimonials about the use of the tool in the design project.
- 14 The study consisted of a design studio project undertaken by second-year graduate students. A cohort of eight students developed five final projects. This was a regular-sized graduate design studio composed of students who chose this particular section class. The groups were created by the students without any instructor's intervention or research requirement.



## Design Briefing

- 15 This studio project sought to redesign the lobby of a small hotel. Due to its prominent role in greeting the guests and establishing the image of the hotel brand, the lobby was regarded as the signature space of the hotel. The project included the actual interior space of the lobby area, the immediate spaces of the vestibule and the entrance including the motor lobby, and the outside areas of parking and pedestrian walkways approaching the entrance of the hotel. The design task included the identification of the connections with other interior areas of the hotel and the functions that would persist in the proposals. Moreover, the architectural redesign could include the complete replacement of the actual lobby, with a solution that would be about the same original square footage that will articulate an architectonic dialogue between the remaining untouched structures (guestrooms, recreational area, and service areas) and the new lobby. See illustration 4.

**Illustration 4: The physical hotel and lobby (left) and the VR hotel and lobby (right)**



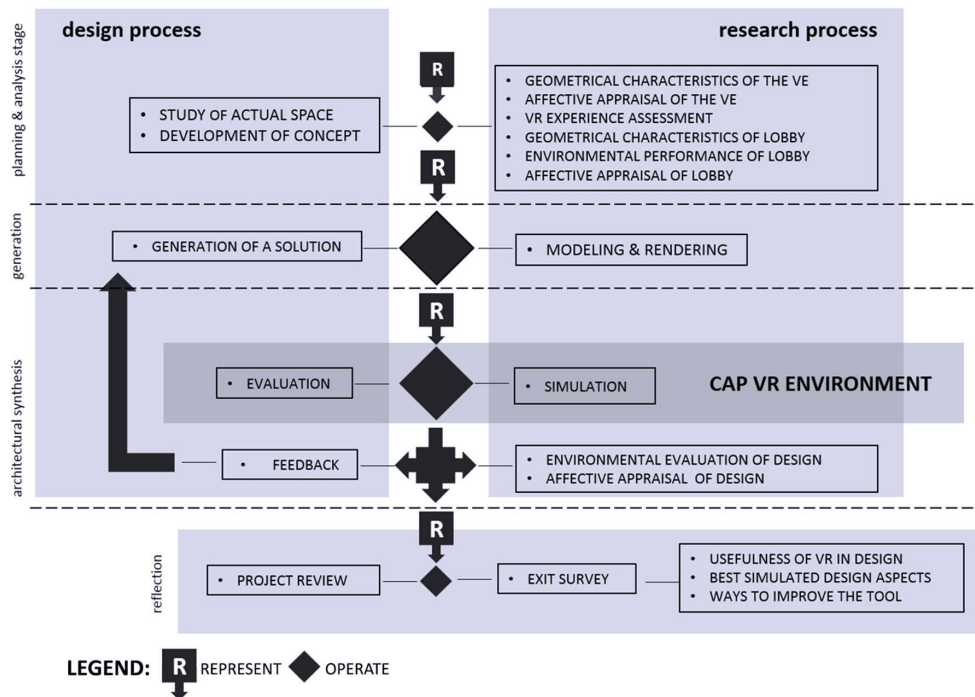
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- 16 The suggested design methodology undertaken by students and the research activities were regarded as independent processes but developed in parallel supporting each other. The design/research methodology in the diagram of illustration #5 depicts two columns: one for the design process that students followed and the other for the research process. The design was performed with cyclical loops in a system that works with representation nodes and activities, after the descriptive model of design in Angulo (1995). The design went through planning & analysis, generation, and architectural synthesis stages. The design activities generated not only more representations to be used in the following design stage but also research data. Partial findings looped several times into a design/research process to generate a more comprehensive result each time. Finally there was a



reflective stage that happened after the review of the final presentation of the projects. It is important to mention that the transparency posed by the research methods affected the students' learning by exposing them to the different research metrics and making them aware of their correlation and impact in the design process.

**Illustration 5: Parallel research and design methodologies**



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## Planning & Analysis Stage

- 17 During the planning and analysis stage the students ascertained not only the physical characteristics of the spaces but also how the spaces felt. That was enabled using two different modalities; in the first modality the students walked through a VR model of the actual lobby (with basic colors and materials in the depiction of the building without furniture) using the CAP VR Environment. See the VR model following this link: <http://capvr.iweb.bsu.edu/videos/compressed/lobby.mov>. In the second modality, the students visited the actual hotel. The students were asked to fill out questionnaires #1 and #2; one for the VR case and the other for the reality. Even though some of the students tackle the project within design teams, all of them responded to the questionnaires on an individual basis reflecting their personal opinion through the questionnaires.
- 18 Questionnaire #1 was prepared after the methodology implemented by Henry (1992) that enquired about:
  - Space dimensions - asking to calculate the geometrical characteristics of the spaces (area, size, proportion, and adjacency),
  - Spatial orientation - asking to recreate a layout and establish spatial relationships between spaces (large/small, location, accessibility, circulation path),
  - First impressions of the space - recalling similar spaces and space effects,



- The affective appraisal of the spaces - list of adjectives describing the affective appraisal of the spaces,
  - Description of the experience using the CAP VR Environment.
- 19 Questionnaire #1 also included a section about their first experience using the VR tool. The affective appraisal of the hotel lobby 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 list of adjectives used in the affective appraisal of hospital waiting areas was adapted to conform to our specific case in the redesign of the hotel lobby.
- 20 The students were asked to fill out Questionnaire #2 during the visit to the hotel. This questionnaire had similar questions to the first, excluding the last part regarding the experience using the CAP VR Environment and adding a portion related to the environmental evaluation of the space. The performance criteria listed in this environmental evaluation were determined in collaboration with the students and discussed until a consensus was reached. The aspects of the environmental evaluation included the volume of space, tectonics, massing, functional performance, circulation, daylight performance, sun incidence, etc. These environmental aspects became the working objectives and performance evaluators of the project.
- 21 For the development of a concept for the redesign, the students were encouraged not only to articulate how to bring solutions to discovered problems but also how to enhance the image of the signature space through the re-branding of the hotel.

## Generation & Architectural Synthesis Stages

- 22 There is a blurry connection between the processes generating the solutions and molding their final condition as a single architectural synthesis. We described these two stages in the same section because of their dynamic elaboration and development.
- 23 The modeling of the solution aiming to resolve the lobby problems could have been conventionally tackled by a design process using flat representations such as sketches, perspectives, layouts, sections, circulation graphs, proximity graphs, visual/vistas graphs and evaluation of square footage, among others. These representations could have informed about the desired functional performance, the ideal circulation, and the expected views as well as the desired connections with adjacent rooms. However the task also required students to consider the redesign of the lobby as a signature space that could articulate the emotion of the guests at arrival, when lounging, when coming and going, and finally when departing from the hotel. Clearly the perception and the evaluation of the space from the point of view of the affective appraisal of the users would involve a more sophisticated tool that could simulate the characteristics of the space beyond flat representations of the design.
- 24 The creation of the alternative solutions was therefore done using conventional 3D modeling applications (i.e. Rhino, Revit, and 3ds Max). The models were assigned standard materials and the scenes became realistic when adding daylight systems and artificial lights. The CAD objects were translated into \*.ive objects—the format used by the Vizard application for real-time display in the CAP VR Environment. The models were then displayed in the immersive environment; allowing the students to evaluate the

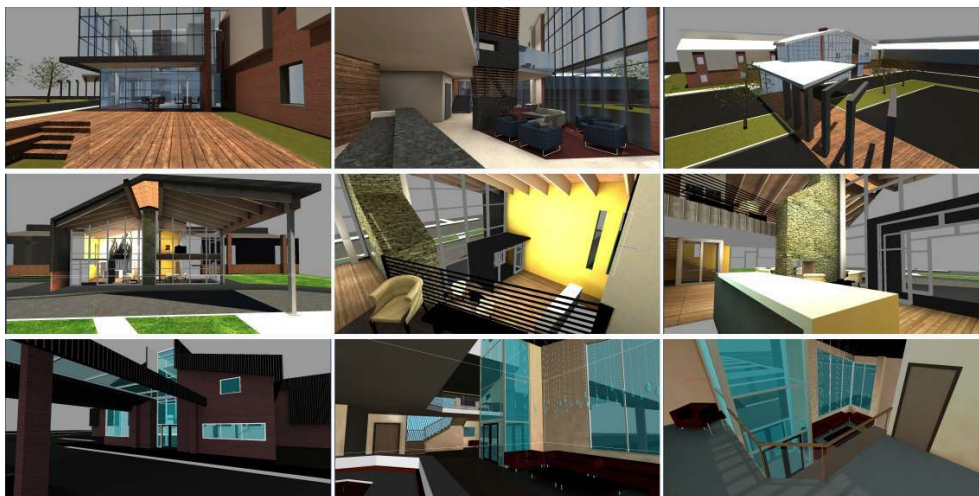


validity of the spatial geometrical relationships between objects. It was well understood how the objects defining the lobby performed in manifold ways as building components providing structural integrity, environmental conditioning, and enclosure for the occupants of the space. These performances were undertaken using analytical tools (i.e. environmental performance simulation for daylighting, circulation graphs, measurement of programmatic areas, diagrams depicting adjacencies, among others) and simulated in the immersive environment through its geometrical characteristics and material connotation. The ability to navigate through the simulated lobbies was key to capture the architectural spatial experience and perceive the esthetical emotion and/or symbolic meaning embedded in the projects. The students were able to evaluate how well the particular combinations of space defining objects could suggest meaningful emotion that correlated with the perceptual objective stated as part of the design concept. The tests and evaluations of the alternatives during the design process provided useful feedback that triggered changes and improvements to the projects before the final presentation.

## Reflection Stage

- 25 A formal final studio review marked the reflection stage, the students used the CAP VR environment to walk around and simultaneously explain their projects. See Illustration 6.

**Illustration 6: Three VR simulation projects of the hotel lobby redesign**



**SOURCE AND COPYRIGHT: KYLE SCHWIND, RACHEL SHETTLE, WHITNEY WARNER, JEFF THORNBERRY, EMILY DESMIT, ALEX POWELL**

- 26 An expert reviewer was invited to participate in this review following the explanations and viewing the projects in the large projection-based screen connected to the VR system. It must be noted that peer review evaluation was also implemented. The students were asked to evaluate each other's projects using Questionnaire #3 that included the combined assessment of affective appraisal and environmental evaluation of the redesigned spaces for each one of the students' projects. Questionnaire #3 was prepared in direct relation to the learning objectives of the rubric of the course. The instrument was executed by the students on a peer-review structure at the same time that an expert reviewer provided additional assessment on the elements of the rubric. The expert reviewer was a faculty member with extensive experience in applying the rubric



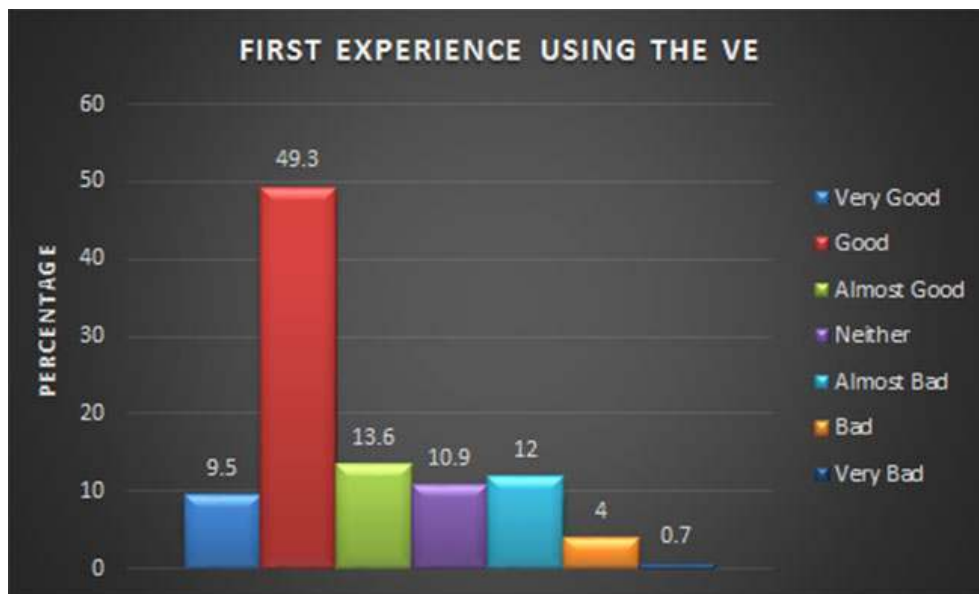
pertinent to that design studio level. Both peer review and the review provided by the expert guided the professor of record in the final application of the course rubric and the final assignment of the grades.

- 27 The development aspects of the projects matched the contents of Questionnaire #3 that included the description of:
- 28 (1) The qualitative aspects of the space
- 29 (2) The environmental performance of the space:
  - a. characteristics of the volume of space
  - b. architectural tectonics (materials, joints, building system, ornamentation, among others)
  - c. exterior massing
  - d. functional performance of the lobby
  - e. circulation (approach, entrance, interior flows, connection to other areas of the hotel)
  - f. basic environmental performance (passive design and energy conservation, comfort)
- 30 See this VR model as an example of the redesign projects of the lobby following this link: [http://capvr.iweb.bsu.edu/videos/compressed/lobby\\_redesign.mov](http://capvr.iweb.bsu.edu/videos/compressed/lobby_redesign.mov)
- 31 The students filled out a survey related to (1) the perception of learning using the CAP VR Environment, (2) the final evaluation of the tool regarding its usefulness in the design process, and (3) recommendations for improvement of the system.

## Data Analysis & Results

- 32 The Likert Scale format was used in all questionnaires. The average rating method was applied to establish the comparison between subjects and projects. The results of Questionnaire #1 in the section describing the experience of using the CAP VR Environment is described in Illustration 7. This illustration shows that the students regarded the use of the VE as a good or very good experience (60%). The questions posed to the students referred to the students' sense of orientation within the VE, whether they felt confused or disoriented within the VE, and how convinced they were in the space while using the simulation.

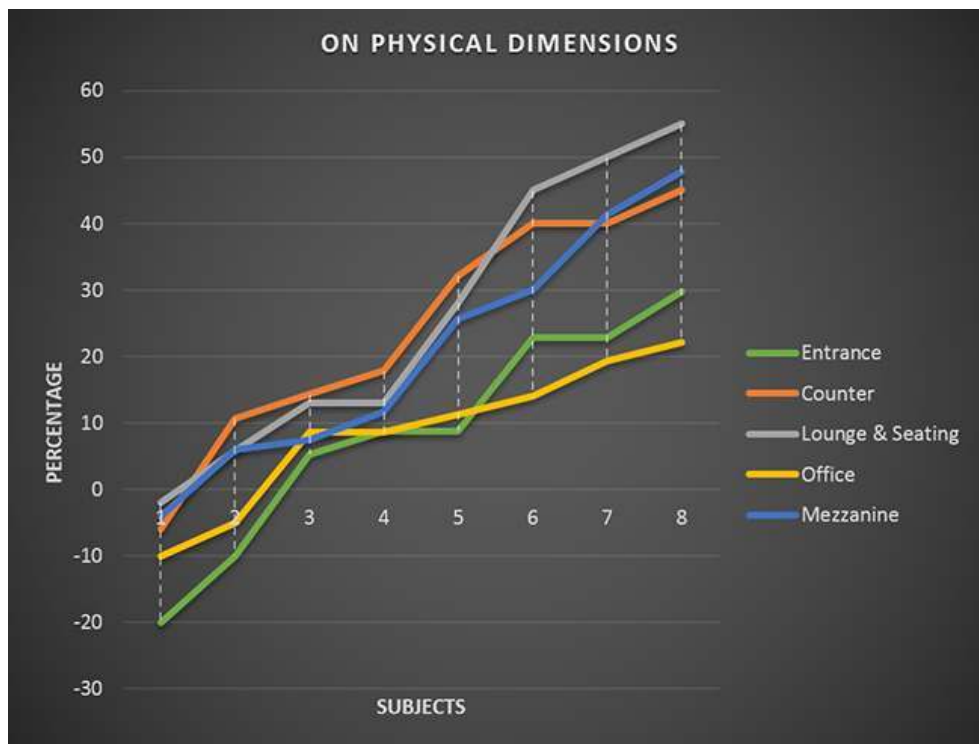


**Illustration 7: Results of the students' first experience using the CAP VR Environment**

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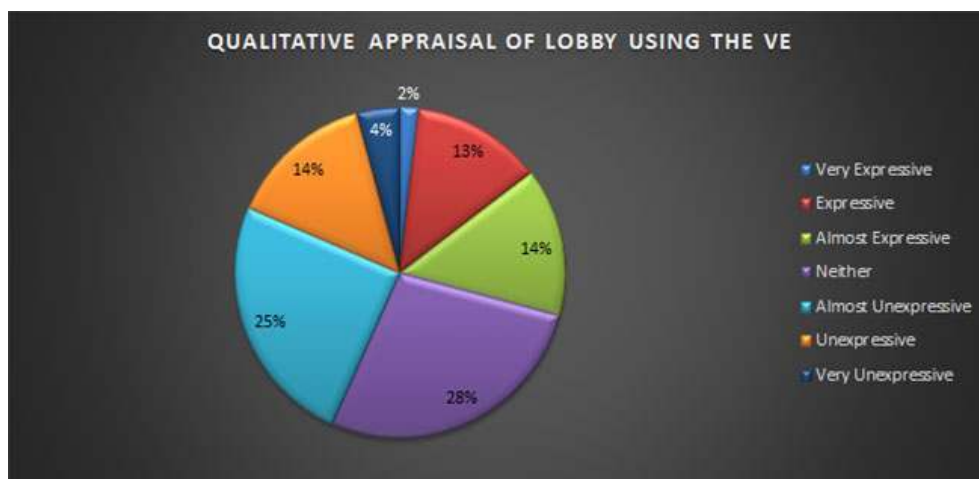
- 33 The results of Questionnaire #1 about the “Estimation of the Lobby Dimensions” using the VE demonstrated that there was a difference between the physical dimensions of the model shown in the simulation of the VE and the ones estimated by the students. Figure 8 illustrates that almost all the students assumed that the spaces in the VE were smaller than in the model. Only two students thought the spaces were larger and they were regarded as outliers. These results are consistent with other studies that suggest that when using an immersive VE the spaces are generally perceived smaller than they are because of the lack of complete spatial reference. The elements that the students mentioned were lacking in the VE included: furniture, more than one avatar, and depictions of realistic material textures. The students were made aware of this “scale phenomenon” and encouraged to take it into account for designing/evaluating their projects in the VR system.



**Illustration 8: Results on the estimation of the lobby dimensions using the VE**

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- 34 In terms of “Spatial Orientation” in Questionnaires #1 and #2, all the students were able to render correct layout plans of the lobby after using the CAP VR Environment or visiting the actual hotel lobby. Regarding the first impression of the space the majority of the students remained neutral regarding whether the lobby was a pleasant or unpleasant space to use. This was also ratified when they were asked to make a qualitative appraisal based on a list of adjectives that would describe the affective qualities of the lobby. See Illustration 9.

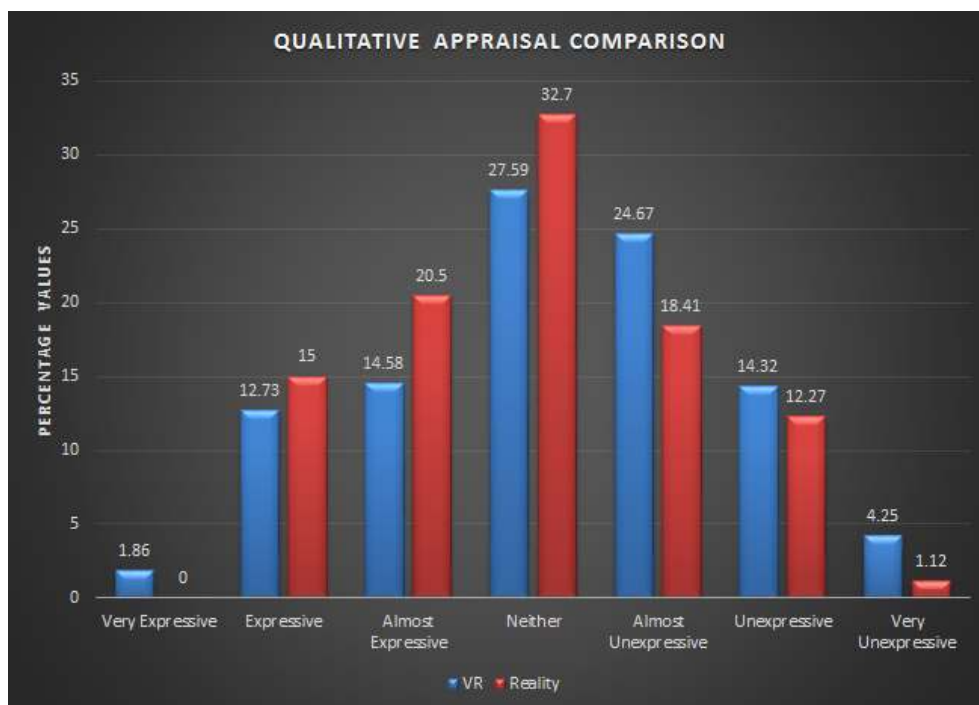
**Illustration 9: Results of the qualitative appraisal of the lobby using the VE**

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- 35 Illustration 9 describes that most of the students depicted the space as almost unexpressive, unexpressive, and very unexpressive when selecting negative descriptors of the list, namely: gloomy, uncomfortable, simple, small, unimpressive, repelling, dark, artificial, cramped, threatening, dull, poorly scaled, and inoperative. The sub-estimation of the size of spaces may have had an impact on the assessment of expressiveness of the lobby where “scale” is an important component of the assessment of expression. The results of the “Affective Appraisal of the Space” using the VE in Questionnaire #1 were compared with results of the affective appraisal of reality of Questionnaire #2. The results reveal that the appreciation of reality and VR are very similar and that they both follow the same tendencies towards a negative appreciation of the spatial quality in the lobby. These results ratify the need for redesign of the lobby. See illustration 10.

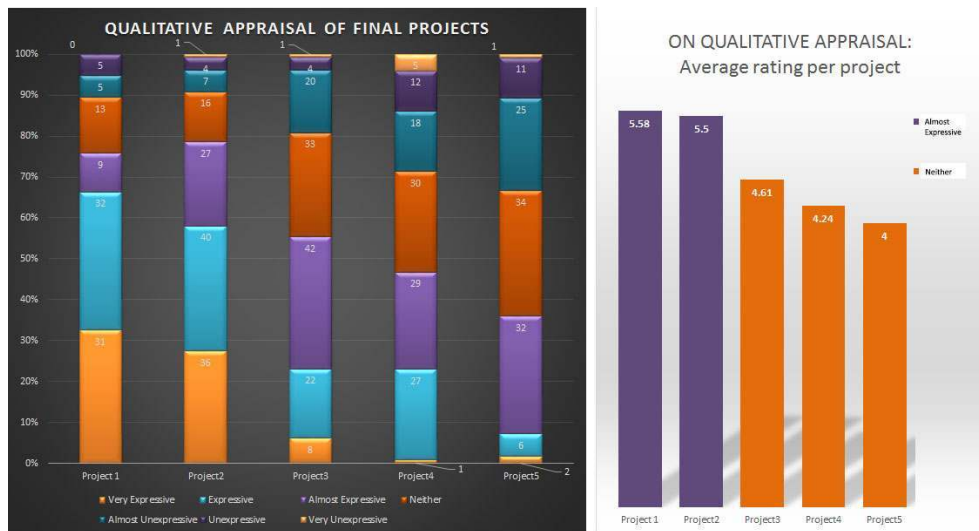
**Illustration 10: Comparative results of the affective appraisal of the actual lobby and the corresponding VE**



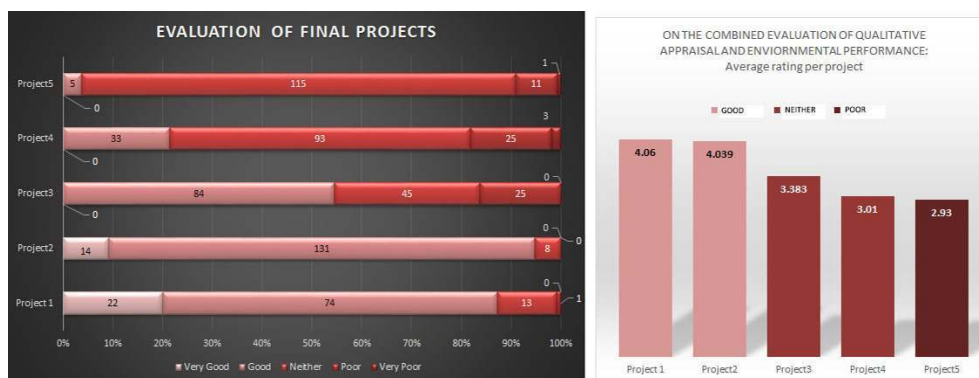
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- 36 Questionnaire #3 made reference to the evaluation of the projects in two separate aspects, namely, the qualitative aspects of the space, and the environmental performance of the space. The results of Questionnaire #3 were tabulated on the basis of projects. It is worth mentioning that some projects were individually produced and some other projects were the product of team work. Illustration 11 shows the percentage values corresponding to the seven categories of expressiveness for the qualitative appraisal. It also shows that the best two projects (in purple) obtained the best average rating of the five projects. These projects, designed and simulated using the CAP VR Environment, were qualified as “Almost Expressive”. Project 3 was also simulated in the CAP VR Environment and was regarded as “Neither” expressive nor unexpressive. Projects 4 and 5 also regarded as “Neither” expressive nor unexpressive were represented using conventional representation techniques.



**Illustration 11: Results of the qualitative appraisal of the final design projects****SOURCE AND COPYRIGHT: ANTONIETA ANGULO**

- 37 Illustration 12 shows the combined results of the qualitative appraisal and the environmental performance sections in Questionnaire #3 gauging the overall quality of the final projects. The results indicated that the same two projects with the highest scores in the qualitative appraisal, were also qualified as “Good” projects. These projects show evidence regarding the satisfaction of the expected learning outcome, namely to demonstrate the ability of the student to identify/manipulate key spatial aspects that promote the design of architectural spatial experiences. These students demonstrated a strong improvement over what they had perceived in the original lobby depiction in the VE and in reality.

**Illustration 12: Results of the combined qualitative appraisal and environmental performance evaluation of the final design projects****SOURCE AND COPYRIGHT: ANTONIETA ANGULO**

- 38 Lastly, the students filled out an online debriefing survey regarding the perception of their learning using the CAP VR Environment; they also added recommendations for improvement of the system. This online survey was anonymous and executed on individual basis. The first question of this survey asked for a level of affirmation to the following statement: “the CAP VR Environment is a useful tool to obtain feedback that no

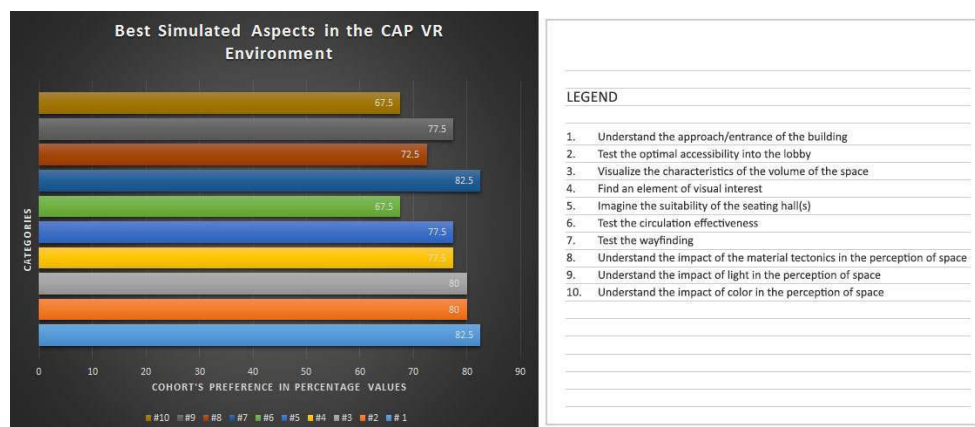


other visualization tool can provide, specifically when assessing the spatial qualities of the design.” The results to this question demonstrated that 62.5 % of the class “agreed” with the statement and 37.5% “strongly agreed”. Some students’ comments elaborated more on their response, as follows:

- Comment 1: It was much easier to experience the space at a human scale when wearing the [VR] helmet. It is useful to validate design intentions
- Comment 2: It is more experiential than a static perspective rendering
- Comment 3: Visualizing the project using the VR software allowed me to understand the spatial environment more so than 2D renderings, which can be manipulated (width, length, views, etc.) to make the space seem larger or more open than it actually is.
- Comment 4: When we create perspectives for a presentation we are focusing a few select views, but when you can walk through the space and look at everything you begin to see the problem areas and scale issues that you just can't get from perspectives. It can make projects better.
- Comment 5: I agree, because not only it is better than regular images of perspectives but also it is more informative and reveals different frames that we didn't consider important.

39 The second question of the debriefing survey was related to the design aspects that were best simulated in the CAP VR Environment, namely (1) understanding the approach/entrance to the building, (2) testing the optimal accessibility into the lobby, (3) visualizing the characteristics of the volume of space, (4) finding elements of visual interest, (5) imagining the usability of seating areas, (6) testing the circulation effectiveness, (7) testing the way-finding, (8) understanding the material tectonics in the perception of space, (9) understanding the impact of light in the perception of space, and (10) understanding the impact of color in the perception of space. The results of this part of the survey as shown in illustration 13 depict an almost even support on all mentioned aspects; the aspects that seemed better served were related to approach to the building and way-finding.

**Illustration 13: Results of the debriefing survey on aspects related to its question 2**



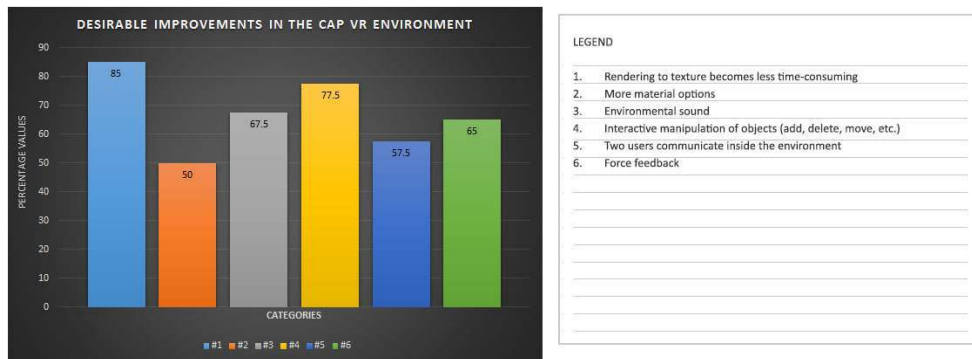
**SOURCE AND COPYRIGHT: ANTONIETA ANGULO**

40 The third question of the survey helped us to obtain the students’ feedback for improvement of the actual VR system. These improvements relate to aspects that would increase the sense of presence in the space and to aspects that would help them to develop the VEs with more ease. As the illustration 14 shows the results of this part of the survey reveal that the students are most concerned with using methods that would



further improve/facilitate/shorten the “baking” process (rendering of lights and textures in the virtual models) included in the creation of the VEs. The second concern makes reference to their ability to modify the designed objects from within the VE; these modifications may include translations, rotations, and other similar transformations. The aspects that would increase the sense of presence in the VE most favored by the students were the addition of environmental sound and force feedback. The least supported improvements were related to collaboration of more than one user within the VE, and the inclusion of additional material textures.

**Illustration 14: Results of the debriefing survey on aspects related to question 3**



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- 41 The overall result of the second study of our research project implemented in the second semester of 2013 has provided us with evidence indicating that most of the students making use of the CAP VR Environment have achieved the learning outcomes related to the manipulation of key spatial aspects that promote the design of architectural spatial experiences and have a positive perception of the process of using the CAP VR Environment to simulate their designs. We have also obtained a better insight into the benefits of using the CAP VR Environment within the design studio, specifically in terms of the aspects that would be most likely supported during the architectural design.

## Findings

- 42 These are the general findings that summarize our work so far:
- The design of architectural spatial experiences have been largely dismissed due to lack of access to adequate representation tools, specifically those tools that tackle the simulation of space in time. Other design tools are only effective in representing quantitative performances but not qualitative issues of architectural spaces. By promoting the use of the CAP VR Environment and further enhancing it through this study we are potentially shifting the conventional paradigm of how we teach and learn in design studios. It potentially shifts the attention from the creation of objects that define space to the creation of space itself and shifts the direction of the design process from outside-in to inside-out. As previously noted in a preceding study (Angulo, 2013) the CAP VR Environment provides powerful technological means that allow students to learn to design through the simulation of the space and the sense of presence achieved within the immersive environment. Students can more easily understand how to relate architectural spaces with architectural places.



- In the United States, games and other entertainment applications have prepared the current generation of students to skillfully learn how to use VR systems. VR systems have become more affordable and substantially easier to use; new generations of VR visors (i.e. Oculus Rift<sup>8</sup>, Samsung GearVR<sup>9</sup>, Sony Morpheus<sup>10</sup>, etc.) will soon become household items and in a very near future, pervasive in most contexts. Our research and development efforts will promote further enhancements in the use of the CAP VR Environment and in turn encourage its extended adoption at the same time that the technology becomes widespread.
- Now more than ever before due to the technological advancements and low costs, VR systems like the CAP VR Environment can be regarded as viable tools among the many that aid design in architecture. We have obtained evidence that those who use this immersive technology have found a new avenue to representing the ephemeral qualities of the architectural spatial experiences and prefer it over the most common day-to-day design tools representing quantitative aspects of the design.

## Future Implementations

43 In the near future we will seek to implement a limited but critical number of functionalities in the current CAP VR Environment. These functionalities are aimed at (1) making the teaching/learning about architectural space more rewarding, (2) making the system easier to use during the design process, and (3) increasing the level of presence within the VE, therefore enhancing current learning outcomes. We will promote the following undertakings:

- Validation of the correlation of the sense of presence and sense of place in the space simulated by the VE by adding environmental sound as a functionality within the VE and produce a series of procedures and recommendations that the students must follow to include this feature.
- Validation of the correlation between spatial performance parameters with spatial effects simulated in the VE by developing specific mapping procedures that will require the students to design spaces with optimal day lighting performance and to relate it to the perceptual effects that will be experienced within the corresponding VEs.
- Design of a methodology for the management of intermediate levels of visualization of the VE. Intermediate visualizations may include the progressive addition of color to geometry, texture to geometry, light to geometry with colors and textures, etc.
- Design of procedures for real-time manipulation of objects within the VE. These manipulations can include translations, rotations, change of color/texture, and instantiation of alternatives. Real time manipulation of design components (i.e. walls, doors, windows, rooms, alternative solutions, etc.) will become an important capability of the system to aid in the fast exploration of design alternatives and to enhance the sense of presence in the VE.

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## NOTES

1. *Entertainment - VR*. Cf. <http://www.britannica.com/EBchecked/topic/630181/virtual-reality-VR/253105/Entertainment> (Consulted on December, 2013).
2. *nVisor SX111 - NVIS*. Cf. <http://www.nvisinc.com/product/products.html?reqview=spec&fid=a0QG0000009NGzCMAW&fname=nVisor%20SX111> (Consulted on November 2014).
3. *CAP VR Environment*. Cf. <http://capvrenvironment.wordpress.com/projects/solar-decathlon-2012/> (Consulted on April, 2013).
4. Cf. <http://www.worldviz.com/products/vizard> (Consulted on April, 2013).
5. The vestibular system, which contributes to balance in most mammals and to the sense of spatial orientation, is the sensory system that provides the leading contribution about movement and sense of balance. Cf: [http://en.wikipedia.org/wiki/Vestibular\\_system](http://en.wikipedia.org/wiki/Vestibular_system) (Consulted on December 2013).
6. Proprioception is the sense of the relative position of neighboring parts of the body and strength of effort being employed in movement. Cf: <http://en.wikipedia.org/wiki/Proprioception> (Consulted on December 2013).
7. Some of the positive effects of a design review implemented in the CAP VR Environment in contrast to the classroom were that (1) reviewers spent more time reviewing, (2) we have more participation of students reviewing, and (3) the interventions were mostly done through opinions and comments rather than plain questions.
8. Facebook's Oculus Rift. Cf. <http://oculus.com> (Consulted on November 2014).
9. Samsung's GearVR. Cf. <http://www.samsung.com/global/microsite/gearvr/index.html> (Consulted on November 2014).



10. Sony's Project Morpheus. Cf. <http://www.sony.com/SCA/company-news/press-releases/sony-computer-entertainment-america-inc/2014/sony-computer-entertainment-announces-project-morp.shtml> (Consulted on November 2014).

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## ABSTRACTS

The paper describes current research efforts in the College of Architecture and Planning (CAP) at Ball State University seeking to assess and make creative use of the instructional potential of immersive simulation implemented in virtual reality (VR) environments. We have conducted graduate and undergraduate design studios using the CAP VR Environment, which is a fully implemented VR environment equipped with a Head-Mounted-Display (HMD) system complete with spatial tracking capabilities. Through these implementations we have contributed to the validation of the use of the CAP VR Environment in design studios and have started to develop teaching/learning methodologies for effectively using this immersive VR environment for aiding novice students in the design of architectural spatial experiences. Assuming that only tools that allow us to simulate presence through time may effectively aid the design of spatial experiences, the CAP VR Environment has been used as such a tool for simulating and testing the effectiveness of architectural spatial experiences. The paper describes the learning outcomes in the application of the CAP VR Environment within the studio setting and the level of satisfaction of the students. It also addresses the potential for future research in the use of immersive VR tools.

Cet article décrit les efforts de recherche actuellement menés au College of Architecture and Planning (CAP) de Ball State University, cherchant à évaluer et à faire un usage créatif du potentiel pédagogique de la simulation immersive mise en œuvre dans les environnements de réalité virtuelle. Nous avons mené des studios de projet dans plusieurs cycles en utilisant le CAP VR Environment, un environnement de réalité virtuelle complet utilisant un système de visualisation par casque (HMD) avec des possibilités de *tracking* dans l'espace. Par ces mises en œuvre, nous avons contribué à la validation de l'utilisation du CAP VR Environment dans les studios de projet, et commencé à développer des méthodologies d'enseignement et d'apprentissage pour utiliser efficacement cet environnement immersif de réalité virtuelle de manière à aider les étudiants novices dans la conception des expériences spatiales architecturales. En considérant que seuls les outils nous permettant de simuler la présence à travers le temps peuvent efficacement aider la conception des expériences spatiales, le CAP VR Environment a été utilisé comme un tel outil pour simuler et tester l'efficacité des expériences spatiales architecturales. L'article décrit les résultats d'apprentissage de l'application du CAP VR Environment dans le programme du studio et le niveau de satisfaction des étudiants. Il questionne également le potentiel pour de futures recherches sur l'usage des outils immersifs de réalité virtuelle.



## INDEX

**Mots-clés:** Expérience spatiale, simulation immersive, casque de visualisation, réalité virtuelle, enseignement de la conception architecturale

**Keywords:** Spatial experience, immersive simulation, head mounted display, virtual reality, education of architectural design