# COMPARING PERCEPTIONS OF OCCUPANT FLOW AND SPACE FUNCTIONALITY IN A VIRTUAL REALITY AND AN ACTUAL SPACE

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***ABSTRACT:*** *As virtual reality (VR) transitions into an everyday tool, there is a need to study how the technology influences decisions during building design. This paper presents an approach to evaluate the reliability and benefits of adopting VR when assessing occupancy flow and space functionality issues. We present findings from a pilot study of 56 subjects. All are students with a background in Building Science. The subjects were guided through a VR walkthrough of the building space and completed a survey about flow and functionality. Then subjects related the value of VR versus the real space. Results indicate a strong positive response regarding the VR experience compared to the actual walkthrough. Other findings provide glimpses of where limitations exist within the VR experience. As an example, the survey results show evidence that subjects could detect differences in the quality of a design but did not perceive a significant difference in flow obstruction risks, when in reality, one corridor is prone to congestion. Most importantly the study provides direction for more comprehensive work. For instance, scaling of objects and the scene in the VR experience has also been identified as a key factor that may affect the decision-making process.*

***KEYWORDS:*** *Virtual reality, BIM, Design Review , Space Functionality, Virtual Design and Construction*

## 1. Introduction

Visual aids are used to assist collaborative designs and communications in the Architecture, Engineering and Construction (AEC) Industry. As one of the most advanced visual aid technologies, Virtual Reality (VR) is gaining popularity in geometry creations and design reviews with its rapid development and integration with Building Information Modeling (BIM) (Xie et al, 2011).

### 1.1 Background

A VR experience is defined as "any in which the user is effectively immersed in a responsive virtual world" (Brooks, 1999). By interacting with virtual models in an immersed environment, users can understand the functionality of the space, detect potential design errors and therefore make better design decisions. VR also provides the opportunity to better understand the client’s design requirements, as virtual mock-ups can create a “better sense of realism” and “have been used to provide a better understanding of a project to end-users and stakeholders, resulting in improved communication” (Heydarian et al, 2015, p. 117).

With that said, comprehensive analysis of VR as a design tool and the extent of its benefit and limitations is still needed. For VR to be widely adopted as a legitimate design-assist tool, it will be likely for the industry to understand these aspects so it is not simply perceived as a gimmick to excite the owner.

### 1.2 Problem Statement

The work described in this paper is the beginning of a longer line of inquiry. In short, the broader research is targeted at better understanding how VR can help design reviews. Generally, one might assume after seeing a design in VR that it is definitely useful, but there is not much clarity as to how useful, when it is useful, and how good the VR needs to be in order to be useful.

This specific work evaluates perceptions within a VR experience and compares the VR experience to the real space. The assumption is made that seeing the actual space would be the best way to assess the design. Thus this study, in part, aims to see if the VR perceptions are comparable to the actual space. If the two experiences elicit similar perceptions, then the assumption that VR helps make good design decisions may be justified. It is preliminary and exploratory, but still some valuable insights were gained and will be reported upon.

The problem scope for this initial and preliminary work assumes an early schematic design without detailed lighting or materials and with lower Levels of Development (LOD) of the BIM model. The design review is specifically focused on space functionality and occupant flow issues rather than being a general purpose evaluation. The reviewers are meant to be people who have some familiarity with buildings but who are not necessarily adept at evaluating a design.

The specific questions being addressed are:

- To what degree do the subjects believe VR is going to be useful as a design review tool?
- Can subjects decipher design issues in the VR experience?

## 2. Literature Review

The literature review focuses on two general themes: conventional design review methods and on use of VR in design reviews.

### 2.1 Conventional Design Review Methods

Regular design reviews in design phases are important for successful project deliveries. According to the Design Council (2013, p.6), design review is "is an independent and impartial evaluation process in which a panel of experts on the built environment assess the design of a proposal". Designers often neglect the holistic view of a project and perceive design scopes with independent visualizations, which may lead to unanticipated continuous cycle of design revisions (Mujumdar & Maheswari, 2018). A good design review procedure will reduce the amount of rework and promote innovative constructions (Soibelman et al, 2003), as well as improving the communications between different disciplines in design and construction phases (CFM, 2009).

Design reviews are typically conducted by expert practitioners in design and development, including lead designers, contractors, clients, and external consultants, etc. (Design Council, 2013) Soibelman et al (2003) developed DrChecks (an online design review checking system) and Corporate Lessons Learned (CLL) system to capture / reuse corporate lessons learned and provide ongoing supports for design review processes. Ping et al (2011) presented a case study of Hong Kong MTR Corporation Projects and demonstrated a systematic design review process in an integrated multi-disciplinary design environment. A Mixed Reality (MR)-based design review prototype was proposed by Wang & Dunston (2013) to improve remote design review collaborations. In 2014, the Facilities Planning & Design Review (FPDR) team at The George Washington University introduced an integrated process made up of 11 teams to the university's design review process (FPDR, 2014).

### 2.2 Use of VR in Design Reviews

Information fragmentation and redundancies have been challenging the AEC Industry in recent years, and Building Information Modeling (BIM) is being widely adopted to foster collaborations and communications (Campbell, 2007). BIM acts as an integrated platform for team members to share and exchange project information through comprehensive object-oriented building models (Eastman et al 2011; Liu et al 2013). Based on BIM models, virtual models are built to integrate BIM and Virtual Reality (VR) technologies and are mainly implemented in pre-construction phases (Xie et al 2011). BIM-enriched Virtual Reality enhances optimization experiences and communications, and helps team members and stakeholders understand project plans and sequences (Dunston et al, 2007; Xie et al, 2011).

Kreutzberg (2015) conducted a study to explore non-specialist user experiences of viewing and navigating a BIM VR model with a head mounted display (HMD). The study indicated that real-time rendered BIM VR models can convey architectural space requirements to non-specialist users with reasonable good results. VR has been proved to be cost-effective and efficient to facilitate design reviews for health care projects. Dunston et al (2007) explored the use of VR to identify how design and physical elements impact processes and safety, and suggested the use of VR to create a database of quantitative and qualitative building elements to help decision-making processes in hospital design. VR was also used with Radio Frequency Identification (RFID) to automate data collections and help the AEC team with construction sequence optimization, site logistics and trade coordination (Xie et al, 2011). To solve the problem that VR headsets mostly provide a solo experience insteading of promoting collaborations in design reviews, Soluis developed a portable immersive system that offers interactive VR experiences for groups without the need for headsets (Innovate UK, 2016). In addition, game engines have been used to enhance VR experiences in design phases. A VR design review system was developed by Shiratuddin and Thabet (2003) using Unreal Tournament (UT) 3D Game Engine to enable real-time manipulation and modification of graphical information. A similar VR application, developed by Cárcamo et al (2017) using BIM models and Unity Game Engine, demonstrated the benefits of using VR in design review processes.

## 3. Methodology

The aim of the study is to investigate whether users' perceptions about a three-dimensional space in a VR environment are similar as their perceptions about the actual space. Gaining a better understanding of user perceptions in the VR environment will be useful to evaluate the efficacy and accuracy of using VR for design reviews.

The methodology section is organized into three parts and follows the research process outline in Figure 1. With the research problem already defined, the first section will highlight the model development and questionnaires. First, data collection process is identified. Then data analysis strategies are discussed. Lastly the VR experience development process is summarized. Figure 1 documents the research process for this study with particular focus on steps taken during the VR experience and space walkthrough. Make note that the team recognized the importance of a quick acclimation period for the subjects, since at the time of the study, most subjects had not used a VR headset before.

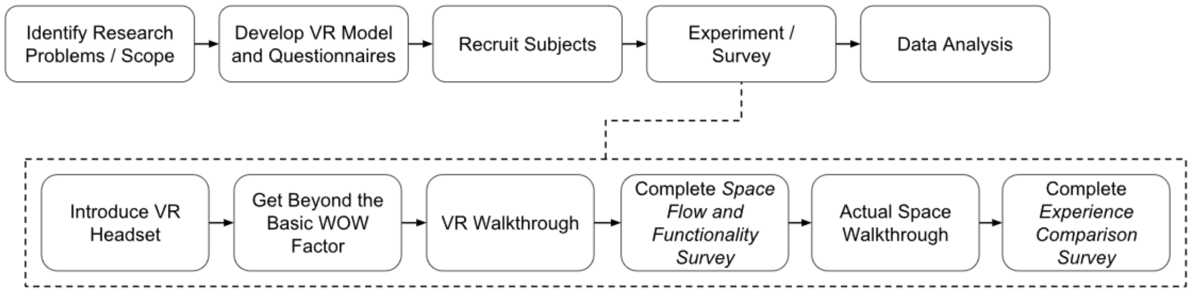


Fig. 1: Flow chart of research steps

### 3.1 Model Development

The VR experience takes place in a study lounge and occupant corridor found within Katherine Harper Hall on Appalachian State University's campus. The site was originally chosen due to some known issues that were impediments to occupant flow and overall functionality.

The space seen in Figure 2 is composed of two occupant flow corridors, a central workspace, entries to faculty office suites and restrooms, and a food prep station. The space being examined is roughly 560 square feet and is a heavily traffic space to the lower level of the building.

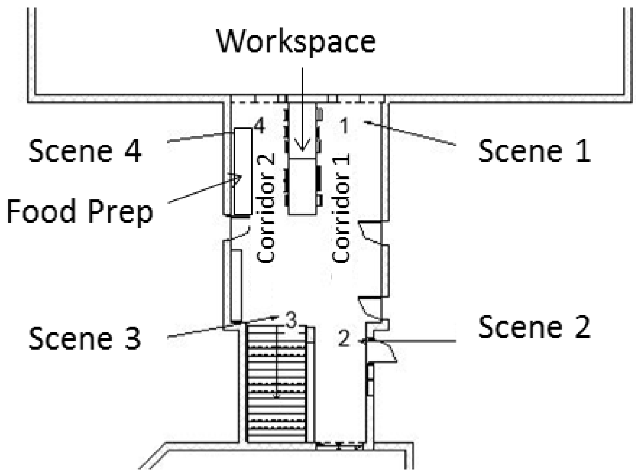


Fig. 2: Floorplan view of the building space used for the study

The consumer version of Oculus Rift (a VR headset) was used as the VR environment platform, and a space model was developed in Autodesk Revit 2017 and 3DS MAX and integrated with the headset through Unreal Game Engine 4. The Oculus Rift system has two motion sensors to track the user's locations and simulate the movements in the VR environment (Oculus, 2018).

Several methods of presenting the VR experience were considered. The primary decision was based on how the subjects will move about the space. The team decided free movement with a controller posed to many risks of user disorientation, dizziness, and nausea. A teleport scheme was chosen for periods where subjects were allowed to move around the space, but even this posed too much risk for distraction. The team settled on creating four scenes in the game engine. The locations are shown in Figure 2. Subjects can still move freely to the extent of the Oculus Rift tether. This scene approach, the team felt, would keep the user on task while experiencing a very novel technology.

To develop the VR environment, the team built a 3D model in Revit, exported it as an FBX file into 3DS MAX, updated some material and lighting elements, exported this updated version as a new FBX file, and finally loaded the file into the Unreal Engine platform. From there, the team wrote a few small scripts and created the different scenes of the study.

Figure 3 shows a view from the VR scene and the actual space. Only basic materials and lighting were incorporated to represent an early stage of the design. *Note*: At the time of this project, simplified methods that currently exist to bring a BIM model into the game engine were not available.

## 3.2 Questionnaire Description

Two surveys were developed for this study. Both surveys primarily used Likert scale rankings. A small selection of preliminary baseline questions were incorporated to ensure a consistent sample pool used in the assessment.

The *Flow and Functionality Survey* consists of two preliminary questions and ten design review questions. There were three sets of parallel questions related to the design of corridor 1 and 2. The themes of these question included:

- Overall design effectiveness for occupant flow and space functionality (Q3 and Q6);
- Specific assessment of occupant flow potential (Q4 and Q7); and
- Identification of obstructions as a problem (Q5 and Q8).

The other four questions asked about specific objectives to the space, including:

- Overall occupant flow capacity (Q9);
- Workspace design (Q10);
- Electrical outlet quantity placement (Q11); and
- Food prep station design and placement (Q12).

*Note*: question numbers are represented by Q#.

The *Experience Comparison Survey* was composed of four questions (as shown below). They asked about how the VR experience compared to the actual walkthrough of the space.

Fig. 3: Shows a comparison of the geometry between the VR experience and the actual space.

- *When using the virtual reality headset, I had a clear understanding of the space and expected uses of the space in corridor one.*
- *The virtual reality experience was just as good as walking through the real space for understanding potential problems.*
- *My perception of the functionality of the virtual space was the same as the real space.*
- *The virtual reality experience was confusing.*

The four questions were intended to be combined to provide an opportunity to make use of parametric statistics in quantifying the quality of the VR experience.

## 3.3 Data Collection Process

A sample of 56 participants was recruited from the students taking Building Science courses in the Department of Sustainable Technology and the Built Environment at Appalachian State University. Each subject was introduced to the VR headset with a script read by the investigator. After the introduction, subjects took a guided VR walk through based on the four scenes of the model and another script read by the investigator. After the VR walk through experience, subjects took the *Flow and Functionality Survey*. Upon completion of this survey, the subject was guided up to the actual space where they were guided through the same four scenes and script from the VR experience. Upon seeing the space in person, the subject then took the *Experience Comparison Survey*.

The 56 individual walkthroughs were delivered over the course of two weeks. Half way through the experiment, a protective face guard was incorporated into the VR headset.

## 3.4 Analysis Strategies

A combination of descriptive and comparative strategies was used to make initial assessments from the data. In general, when comparing data, the Mann-Whitney statistical test was employed.

### 3.4.1 Experience Comparison Survey

The primary purpose of the *Experience Comparison Survey* was to give subjects an opportunity to compare the VR walkthrough experience to the actual walkthrough experience. The Experience Survey was composed of four questions, all with a 7-point Likert scale.

With the data, basic descriptive statistics is primarily used to characterize the general consensus of the population. A summative assessment of the four Experience Survey questions allows for parametric analysis outputs describing the general feeling of the sampled population.

### 3.4.2 Flow and Functionality Survey

The *Flow and Functionality Survey* was the primary tool used to address how well subjects could decipher and interpret design issues from the VR experience. A few lines of inquiry will be presented from the survey. First, design quality is treated as an independent variable and Corridor 1 and 2 are treated as different groups. A series of parallel questions [Q3 with Q6; Q4 with Q7; Q5 with Q8] were used to understand what the subjects noticed. The Mann-Whitney statistical test was used to check if there was any statistical difference in the sample's perception of design issues between the two corridors.

Q11 in the survey was originally meant to assess if subjects could identify a known problem related to electrical outlet placement within the space, but before the project was conducted, the space was altered to resolve the issue. In response, question 11 still asks about the electrical outlets, but no outlets were shown in the actual VR experience. The question was then used to gauge how people might respond if there was nothing to actually respond to in the VR experience.

Q11 was then compared to other questions (Q10 and Q12) from the survey to assess if there was any statistical difference in how the subjects responded. The Kruskal-Wallis test was used for this assessment.

### 3.4.3 Headgear Treatments

An opportunity arose to explore whether a protective face guard altered a subject's response to the VR experience. This was possible because roughly half of the subjects (25 out of 56) participated by directly wearing the VR headset, while the other half put on a face guard before wearing the VR headset. The face guard is meant to prevent potential health risks due to direct contact between the headset and subjects' faces.

As such, a comparative test was conducted to assess whether there was any statistical difference between treatment 1 and treatment 2. Again, Mann-Whitney tests were performed on a subset of questions from both surveys to see if there was any variation between the two treatments. Subjects 1-25 and 30-55 composed the pre and post treatment samples respectively.

# 4. Results and Analysis

The results and analysis will be broken into three sections. The Experience Comparison survey, Flow and Functionality Survey and the headgear treatments will be discussed separately.

## 4.1 Experience Comparison Survey

After subjects conducted both the virtual and physical walkthrough of the space, they were asked to compare their experiences. Figure 4 highlight how the subjects generally felt very positively that the VR experience was equivalent. Using a summative Likert scale, the results strongly indicate that the subjects believed the VR experience was very similar to the real walkthrough with over 88% indicating either agree or strongly agree.

## 4.2 Flow and Functionality Survey

The results from the *Flow and Functionality Survey* begin to shed light on what people experience in the VR

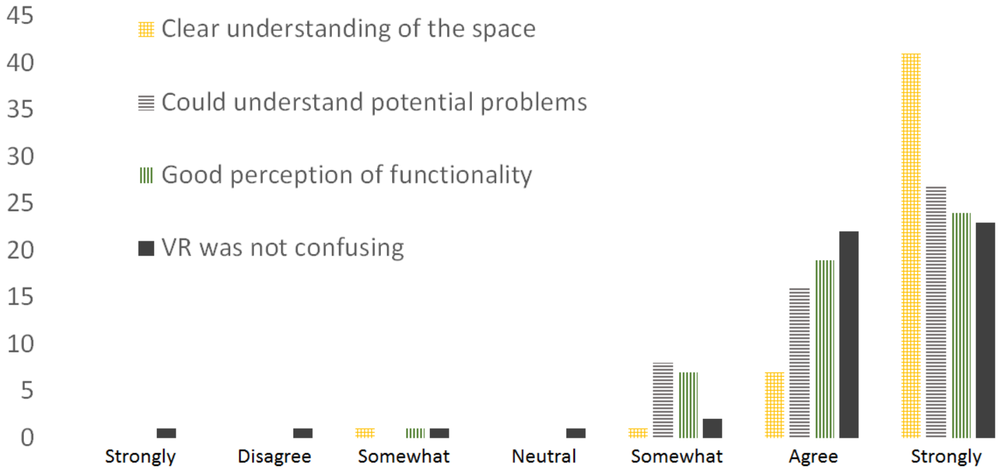


Fig. 4: Adjusted results from the experience survey

setting and if they can distinguish issues or not. These result are preliminary with some significant limitations that will be discussed, but they should still be useful in guiding future work.

### 4.2.1 Comparison of Corridor Design Issues

Results shown in Figure 5, to a modest degree, indicate that the subjects felt Corridor 1 was better than Corridor 2 in regards to occupant flow. Questions relating to overall design effectiveness (Q3 and Q6) and design for occupant flow (Q4 and Q7) both indicated a significant difference with p-values of 0.00013 and 0.0054 respectively. With that said, Q5 and Q8 asked if the corridors were prone to obstructions, and in this case, responses were not significantly different with a p-value of 0.60.

*Note:* Q6 had to be normalized from a 5 point to a 7 point scale, as such those result should only be seen as preliminary indicators. These results may suggest that subjects can detect a difference in design quality. Based on the obstructions question though, perhaps limitations exist when it comes to pinpointing the problem.

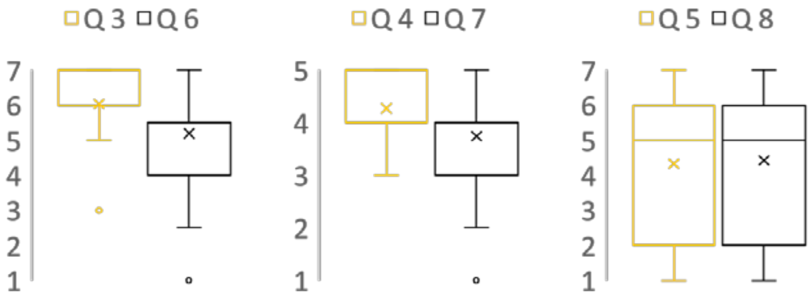


Fig 5: These box plots highlight the variation in response regarding the two walking corridors in the study. Q3, Q4, and Q5 were in regards to Corridor 1. Q6, Q7, and Q8 were in regards to Corridor 2.

### 4.2.2 Electrical Outlet Responses and Other Design Elements

As was previously indicated, there were no electrical outlets shown in the VR experience, but the subjects still indicated that the outlet position and quantity were sufficient. Figure 6 show the distribution from this question. A few possible reasons for this response profile include:

- Confusion about the question;
- Responding to the novelty of the VR experience; and/or
- Leveraging prior experience with the space.

When comparing this response profile to Q10 and Q12, there is no statistical difference in how the sample responded to the different questions, resulting in a p-value of 0.423. Additional thoughts on this observation are offered in the Discussion and Conclusions section.

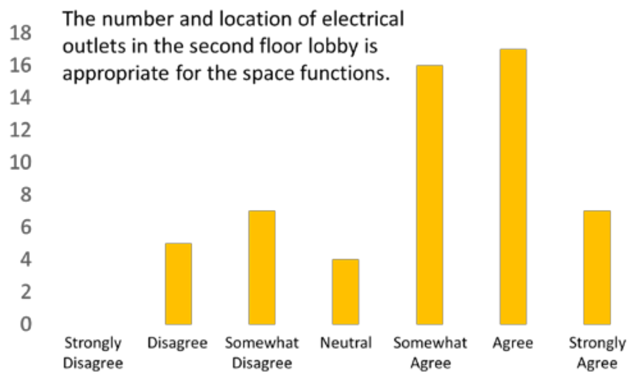


Fig. 6: Responses from Q11 when no electrical outlets were present

## 4.3 Headgear Treatments

Face guards were used half way through the project, offering an opportunity to compare responses between the two treatments. Results indicate that there was no significant difference in how subjects responded to the VR experience or in their comparison between the VR vs real walkthrough. No result had a p-value lower than 0.40 based on the two treatments of the VR experience.

# 5. Discussion and Conclusions

This work is preliminary and primarily meant to shed light on the development of more comprehensive studies that will contribute toward our understanding of how and to what extent VR design reviews can improve building design decisions. The hope is that the technology will result in users coming to the same conclusions that they would come to by actually walking through and interacting with the eventual space.

## 5.1 Limitations

As this study was a small-scale pilot project, there were some limitations. Due to time and resources, the breadth of the subject pool was restricted to only students taking classes from the Building Science program at Appalachian State University. This limits the generality of the conclusions, but is useful for defining qualities about this specific population, which might be of value for future work.

The survey instrument did not go through a thorough process of validating questions, and was intentionally kept to less than 20 questions to help the investigators carry out the project for the 56 subjects. As such, conclusions cannot be made from all of the questions.

The space selected for the VR experience was chosen in large part because there were very significant issues with electrical cords being draped in the corridors for computers in the study area. Between the selection of this space and when the survey was delivered, electricity was rerun on the workspace table, eliminating the issue. This altered how the electrical outlet question was used.

One issue that restricts the conclusions to the flow and functionality survey is that all of the subjects had some prior familiarity with the space chosen for the VR experience. In future work, it will be important to select subjects that do not have this prior knowledge and potential bias. For the current study, it is impossible to know if the subjects were responding purely to the VR experience or if their prior knowledge influenced their responses to the *Flow and Functionality Survey*.

On the other hand, this prior knowledge may strengthen the *Experience Comparison Survey* because the subjects knew what the space does look like, and one could reason that the subjects would have noticed any significant issues.

## 5.2 Conclusions and Future Work

For at least while VR is new to its users, the results from the protective mask analysis provide some level of assurance that it will not be a negative factor when delivering future studies in the VR environment. With that said, the newness of the tech may allow subjects to forgive the inconvenience of a protective mask, but perhaps in the future, this could become a distraction.

The VR experience had very real issues that made it different from the actual space. For example, scaling of certain objects like the microwave was not correct. Despite these inconsistencies, the results overwhelmingly suggest that the subjects felt the VR experience was a strong and useful match to the actual walkthrough.

A few questions arise:

- To what degree does scale matter for the overall scene and for objects within the scene in the context of a design review?
- Can people draw conclusions that are the same as being in the real space if there are scaling issues in the VR experience?
- What are the scaling tolerance levels for VR scene developers when making an experience to assist in design reviews?

Current and future work look to provide more evidence into these elements of VR for design reviews.

## 6. Acknowledgements

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