Enhancing Health and Performance of Students in a Learning Environment through a Digital Pre-Occupancy Toolset

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The learning environment, including its physical design elements, has been shown to contribute significantly to student performance outcomes. However, the existing literature about such effects relies primarily on casual observations rather than on rigorous empirical testing. Broad trends in environmental impacts have been noted, but there is an overall lack of empirical evidence about how specific aspects of the physical environment can affect learning performance. This research aims to develop a digital pre-occupancy toolset to understand the impact of different interior design variables (independent variables) on learning performance (dependent variable). In this multi-stage study, we first use interviews with students and educators to help identify hypotheses about the relationship between specific interior design variables and effective learning experiences. We then develop a digital toolset to quantitatively measure the effect of these design variables. The toolset is based on an Augmented Reality approach. Wearing a virtual-reality headset allows participants to experience video footage of the same classroom lecture, but with specific features of the environment altered (ceiling height, views and visual access to nature, and wall texture). Various quantitative tests will be conducted to measure learners' responses to these three variables and their capacity to assimilate lecture material within the different parametric environments. Identifying and testing these specific elements among different student groups can help interior designers to better succeed in creating supportive spaces for learners. The digital toolset is developed with a consideration toward flexibility, so that it can be readily adapted by future researchers and designers to investigate the potential effects of additional interior design variables and their relationship to other human factors (such as stress responses, visual memory, etc.).

LEARNING ENVIRONMENT

The learning environment, simply put, is the context in which learning takes place. It includes social, cultural, temporal, physical (built and natural), and sometimes virtual aspects [1, 2] . Student performance has been shown to have a significant relationship to the quality of the learning environment [3]. Poor-quality environments can create barriers such as impaired concentration, boredom, and claustrophobia, and thereby lead to poorer educational outcomes. A high-quality learning environment, in contrast, supports engagement and inquiry, and accounts for a diverse range of developmental needs, learning styles, and abilities.

Despite the well-established link between learning environments and student outcomes, the specific elements within these environments that affect students have not been rigorously broken down and empirically investigated. This is especially true in relation to the architectural environment. Temple [4] notes that, "Where connections between the built environment and educational activities are made, the basis for doing so tends to be casual observation and anecdotes rather than firm evidence." Further research is needed to help identify the individual elements of the physical environment that might be important from a design perspective in order to help support student achievement [5, 6, 7].

The work that has been done in this area suggests, at best, a number of general themes regarding the optimal design of learning spaces. Perhaps the most dominant theme is that these spaces need to be flexible, both pedagogically and physically, so that they can be adjusted to reflect the nuances of different knowledge areas and specializations, as well as different learning styles [8]. This awareness reflects the growing understanding among teachers of the importance of active and collaborative learning, student-faculty interaction, enriching educational experiences, and opportunities for intellectual creativity. Along with this emerging new pedagogy comes an increased interest in transforming traditional classrooms to a new learning environment that can more easily accommodate collaborative and active learning in a technology-rich setting [9].

Other specific factors that have been associated with higher student performance in the existing literature include the incorporation of naturalness (in light, sound, temperature, air quality, and links to nature) [7, 10, 11]; learning environments that create a greater sense of individuality, ownership, and flexibility [7,12,13] ; and environments that provide greater stimulation and sensory impact [7, 14, 15].As can be seen in the dating of these citations, this is a relatively new area of study, and there is a lot of hope in the literature that future investigations can help to further isolate the relevant factors and contribute to learning outcomes by implementing these concepts and techniques.

PERFORMANCE-BASED DESIGN PROCESS

The design process can be understood as a procedure of defining problems, generating alternatives, and then evaluating these options [16, 17, 18]. "Performance- based" or "high-performance" design is a method for increasing the effectiveness of this process through selecting specific variables for evaluation and implementing a plan that leads to rigorous, successful exploration of the available alternatives [19]. This normally takes place during the early stages of design process, when there is more opportunity to enhance the value and performance of a proposed project in comparison with the later phases [20].

The conceptual strategies used in performance-based design can range from the informal to the exhaustive. The main goal is to discover architectural solutions that will help to optimize the beneficial effect of built environments on human health and wellbeing. This evaluative process, in its emphasis on performance, requires a significant transformation in traditional approaches to design, as all decisions are examined from a perspective of the desired performance outcomes and the testing of effective solutions [21]. Clevenger and Haymaker [22] described six design strategies relative to high-performance building, which include (a) validating the model's ability to represent the real world, (b) screening for factors that influence performance, (c) sensitivity to the desired outcomes, (d) an awareness of uncertainty and the potential effects of risks, (e) optimization for the best performance, and (f) trade-off analysis. One of the most promising approaches to implementing this process is through the use of virtual analysis using digital platforms.

DIGITAL PLATFORMS AS A RESEARCH TOOL IN THE DESIGN PROCESS

A number of different virtual-reality platforms have been created to aid in architectural modeling and Building Information Management (BIM) processes, in order to support the goals and practice of performance-based design. A few of the most prominent examples include Autodesk Showcase®, BIMx®, Lumion3D®, and LumenRT®. All of these platforms provide capacities through which the viewer is able to digitally experience a space using animations and interactive walk-throughs. The customization of these views is limited in existing platforms, however, and interactivity is restricted to a singular viewpoint determined by the software's preconfigured settings. The user must switch between preset views, or between different software packages, in order to obtain a more comprehensive experience of the virtual space.

The limited functionality of standard architectural software in the area of design research and evaluation is currently leading to the development of new tools to address these needs. One such approach is Augmented Reality (AR), which allows the user to experience both actually existing spaces and virtual elements simultaneously. Sørensen [23]explained that, in screen-based virtual reality presentations, "even though one moves through digital models that closely resemble a reality, they are experienced as scale models. AR is a further development of the technology and is understood as a combination of digital models and the physical world." Kim and colleagues [24] likewise defined AR as involving "the human perception with both real and virtual information sources, and accordingly, AR research in architecture and design is an inter-disciplinary research between the AR technology, human factors, and design."

In recent years a large number of design researchers and other architects have begun to incorporate AR technologies into their work. Kumar and colleagues [25] developed an AR interface for conducting experience- based design reviews of health facilities. Keough and colleagues [26] created a mobile application that uses AR to allow for BIM model-viewing and mark-up while in the field. Chung and colleagues [27] proposed an AR system that allows users to see historical sites superimposed over the current environment, and to navigate these models and their information in real-time. Other architectural researchers who have contributed to the development of AR approaches include Santos and colleagues [28], Pauwels and colleagues [29], Shiratuddin and Thabet [30], Yan and colleagues [31], Hematabadi [32], and Altabtabai and Yan [33].

The majority of these studies apply the AR environment for design-review purposes. However, at the current time there is minimal existing research that addresses specific human-related factors, such as educational outcomes, as a component of these virtual design reviews.

RESEARCH OBJECTIVES

Given the lack of empirical evidence about how specific elements of the physical environment are related to learning outcomes, as well as the minimal research into using digital platforms for pre-occupancy evaluation of human factors, this project aims to fill a significant gap in the existing literature. The goal of this work is to develop a digital pre-occupancy toolset for use in design that will help to enhance student performance in learning environments. The primary objectives of our research are:

Objective 1. Develop hypotheses about the relationship between selected interior design variables and the effectiveness of learning experiences.

Objective 2. Develop a pre-occupancy digital toolset through which designers can evaluate the impacts of various interior architecture elements on learning outcomes.

Objective 3. Assess and verify the impacts of recognized interior design variables on learning outcomes.

RESEARCH QUESTIONS

The specific research questions that the study will answer are follows:

RQ1) How does the height of the ceiling affect learning outcomes?

RQ2) How do window views and visual access to nature affect learning outcomes?

RQ3) How does the classroom wall texture affect learning outcomes?

RQ4) What are some of the wider benefits of a digital design optimization toolset that can be applied in learning environment design in the future?

METHODS

Objective 1. Develop hypotheses about the relationship between selected interior design variables and the effectiveness of learning experiences.

Based on the literature review, three interior design variable were selected for investigation in this initial study: classroom height, views and visual access to nature, and classroom wall texture. To develop hypotheses about the relationship between these interior design variables (independent variables) and learning performance (dependent variable), we will first conduct interviews with interior design students and interior design instructors. A total of 20 interviews will be conducted (10 with students and 10 with instructors). The design students for the interviews will be recruiting from the investigators' academic institutions, and the instructors will be recruited through the Washington State University Student Center. The qualitative analysis of the resulting data, combined with the results of a detailed literature review, will provide the initial hypotheses that will be investigated in a more rigorous fashion in the later portions of the study.

Objective 2. Develop a pre-occupancy digital toolset through which designers can evaluate the impacts of various interior architecture elements on learning outcomes.

The digital toolset will allow designers to modify specific architectural elements and measure participants' reactions to those changes. The ideal context for this research into learning environment is one that allows the experiment to happen within the complexities of an actual interior space. However, it is also necessary to maintain a digitally controlled, parametric set of interior variables in order to obtain reliable quantitative data. With these two factors in mind, it was determined that the best setting for the experiment would be to incorporate a digital version of the interior design variables that were under investigation into the real context of an existing learning environment , using an Augmented Reality approach.

Combining the digital representations and real environments is a significant technical challenge, especially given the potential for different viewpoints and different focal distances. In order to accomplish this task, video footage from a headset-mounted camera will be augmented with digital representations. The Autodesk MAYA software package will be used to recreate the exact same camera movements of the video footage within a virtual space, using an exacting process known as reverse kinematics. After combining the real and virtual images, Samsung's virtual reality headset (Figure 1) can be used to allow the participants to experience different interior design variables such as lighting, views to nature, color, wall texture, ceiling texture, and material, within the same video image. This parametric interior environment can be modified and adapted to the set of variables that have been selected for this study. It can also be further adapted by other investigators to examine whatever variables they are interested in.

Objective 3. Assess and verify the impacts of recognized interior design variables on learning outcomes.

In the final phase of the study, the digital toolset will be tested and the results will be reported. The investigators will reserve a room in the student community centers of their respective universities, and will recruit students to participate in this 70-minutes experience. Drawing on the advantages of face-to-face recruitment, student organization involvement, and the attractiveness of a virtual-reality experience, we hope to recruit at least 150 participants. These participants will be asked to complete a written questionnaire to provide demographic and background data, and to indicate their conscious attitudes towards particular types of interior design spaces. Then, the participants will be asked to experience a parametric, 3D-generated educational environment using the Augmented Reality headsets. In a random order, they will be exposed to the same educational environment with a different ceiling height (high ceiling or low ceiling), three different views to nature (straight view to nature, side view to nature, or no view to nature), and three different wall textures (horizontal wall pattern, complex geometry pattern, or no pattern)—for a total number of 18 different possible learning environments. Their responses to those changes in the environment will be measured using a Likert-scale questionnaire developed from the interviews results.

Finally, the participants will be allowed to roam independently and continuously throughout the virtual learning environments, to explore at their leisure and observe all of the design interventions that are used in the study. As the participants explore different parts of the learning environment, they will be taught actual educational lessons, followed by questions to test their learning. The results from this quantitative evaluation, when compared to the more constrained participant experiences in the first phase of the Augmented Reality experience, will allow for a triangulation of data, increasing its validity and helping to provide a more nuanced outlook on the design factors that are being investigated.

PILOT STUDY RESULTS

The research concept described above emerged during the course of a multi-disciplinary collaboration involving School of Design and Construction, Washington State University. In the pilot study phase, 30 students from the design studio were selected to participate. A classroom in the author's institute was selected for the setting of the augmented reality application.

The three architectural factors including views to nature, wall texture, and classroom height investigated in pilot study. There is undoubtedly a wider range of interior architectural features that contribute to learning performance levels beyond these three identified variables; however, based on patterns discovered in earlier research, we believe that these are central candidates for implementing effective performance-increasing interior architectural interventions.

As described above, the participants filled out a background survey and then explored the Augmented Reality representation while their stress levels were monitored. Descriptive statistics were used to summarize important features of the resulting data, such as the mean (average) responses, and further analysis and hypothesis-testing was conducted using parametric (ANOVA) and non-parametric (Chi-square) statistical methods.

Figure 1: Samsung's virtual reality headset will be used to allow participants to experience the Augmented Reality simulation..

DISCUSSION

In this research, a prototype Augmented Reality platform is developed as an instrument for evaluating the relationship between interior design factors and student learning. There are numerous potential applications of this platform beyond the specific design features addressed in this study.

As new technology allows architecture to deviate from its traditional forms, the potential for redesigning stressful interior space will only continue to increase. However, studying the relationship between this new potential for experimentation and its human effects can be a difficult task. We propose approaching this problem in the course of the established architectural decision-making process by developing toolsets to help evaluate human responses to proposed designs. The prototype platform created in this study to evaluate human stress in relation to particular design features is a first step toward advancing this goal. This process can promote the philosophy of "critical making" that reconnects the conceptual domain of contemporary design computation with the broader study of human experience in the humanities and social sciences [34].

The results from the pilot study, while limited in their scope, support the overall hypothesis that there is a correlation between learning outcome and architectural form perception, and that this correlation can be evaluated in an Augmented Reality environment. The case study described here evaluated anxiety responses associated with three specific architectural design variables among 30 design students. However, the platform can be adopted and developed to study any number of specific aspects of the built environment. The demographic data that was collected can also be adjusted to focus on any specific populations of concern, helping to promote healthier and less stressful urban environments for all. It can thus enable designers to make more informed decisions, promote public health through their work, and respond better to public needs.

CONCLUSION AND FUTURE DIRECTION

A prototype Augmented Reality platform was developed as an instrument for evaluating the relationship between architectural form and human factors such as stress responses. This paper briefly summarized the development of this platform and a preliminary study that was used to evaluate its potential. The results from the pilot study in this research indicate that there are verifiable relationships between specific architectural variables and human stress, and that these relationships can be evaluated using Augmented Reality approaches

There are numerous potential applications of this approach for evaluating human factors in contemporary architectural development. Planned future work includes conducting broader case studies with a wider range of participants in order to validate the pilot results presented here, as well as expanding the platform to study other types of variables. Additional architectural factors will be examined, as well as other types of human factors such as the development of visual memory. We are currently validating the user interfaces and human-factor monitoring process of the platform by conducting an ease-of-use survey.

Due to the large variety of types of education and the specific environments of each, it makes sense to develop a flexible tool to assist in research and design efforts in this area. There are currently several evaluation tools that are used for post-occupancy approaches to this problem, such as Sanoff's assessment tool [35], Wolff's problem-based design model [36], and the OECD Evaluating Quality in Education Spaces pilot project [2]. Findings from studies based on these post-occupancy methods can be valuable, but they provide only limited results for school improvement and education effectiveness. Part of their drawback is a lack of flexibility, as they were created to study particular aspects of the learning environment. The current research proposes to develop a pre-occupancy design tool that will allow for a greater range of investigation and understanding in regard to the impact of interior design elements on student learning. The intended users of this tool are researchers and interior designers, and it is hoped that its can provide the following benefits:

1) Improvements related to the physical learning environment. The research project will generate guidelines to inform the design of educational facilities, which will be shared with building code-and-standards organizations (e.g. the Learning Environments Evaluation Program). It is anticipated that the outcomes of the research will reveal evidence that could be useful for informing the design of the learning environment in ways that improve student performance, social and communication skills, health and well- being, and active learning engagement.

2) Benefits to the practice of educational design. The research results will help designers to improve their efforts and hone their skills. The digital tools developed in this research are generalizable and can be used by interior design practitioners in the early stages of the design process to help identify higher- performance solutions.

3) Benefits to society. The improvement of learning spaces and learning outcomes has the long-term potential to create benefits including greater motivation for younger generations to pursue lifelong learning, better workplace preparation, more effective and efficient use of learning facilities, the cultivation of entrepreneurial skills, and more active citizenship.

4) The promotion of teaching, training, and learning. Our project is a collaboration between two nationally recognized academic interior design programs. It will include student participation in the research process and, as an investigation into the design of educational facilities, it may have a direct impact in the design- based learning environment for the participating faculties and students.

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