buildings

Article

The Effect of Personal Characteristics on Spatial Perception in BIM-Based Virtual Environments: Age, Gender, Education, and Gaming Experience

Bongjun Ji [1], Julian Kang [2], Chaehyeon Kim [1], Sojung Kim [3], Yooseob Song [4] and Jaeheum Yeon [1,*]

[1] Department of Regional Infrastructure Engineering, Kangwon National University, Chuncheon 24341, Republic of Korea; bjji@kangwon.ac.kr (B.J.); chaehyun@kangwon.ac.kr (C.K.)
[2] Department of Construction Science, Texas A&M University, College Station, TX 77843, USA; juliankang@tamu.edu
[3] Department of Industrial & Systems Engineering, Dongguk University, Seoul 13557, Republic of Korea; sojungkim@dongguk.edu
[4] Department of Civil and Environmental Engineering, University of Alabama in Huntsville, Huntsville, AL 35899, USA; ys0029@uah.edu
* Correspondence: jyeon@kangwon.ac.kr

Abstract: In the Architecture, Engineering, and Construction (AEC) industry, virtual environments are being utilized to enhance communication among stakeholders and improve visual comprehension. However, stakeholders possess diverse personal characteristics which can affect their spatial recognition ability in virtual spaces. Despite the potential impact of these individual traits, related research still needs to be more comprehensive. Therefore, this study analyzed how each individual's characteristics influence spatial recognition in a Building Information Model (BIM)-based virtual environment. A quantitative methodology via a survey was employed to investigate the influence of personal factors such as age, gender, education level, and gaming experience on spatial recognition. In a 3D virtual corridor using BIM software, 76 participants were asked to navigate the corridor using a controller and count 23 sprinklers. Of the 76 participants, 30 responses were selected for the statistical analysis. The results demonstrate that age, gender, and education level did not significantly affect spatial recognition in the virtual environment. Conversely, participants with gaming experience tended to perceive spaces in the virtual environment more accurately and realistically, showing a statistically significant difference. This outcome suggests that gaming experience is crucial in enhancing spatial recognition ability in virtual environments. The findings from this study offer critical insights into the impact of individual characteristics on spatial recognition, providing valuable information for the future practical use of BIM-based virtual environments, and can subsequently assist in discovering efficient communication methods among stakeholders.

Keywords: BIM; virtual environment; spatial perception; survey; statistical analysis

check for updates

Citation: Ji, B.; Kang, J.; Kim, C.; Kim, S.; Song, Y.; Yeon, J. The Effect of Personal Characteristics on Spatial Perception in BIM-Based Virtual Environments: Age, Gender, Education, and Gaming Experience. *Buildings* **2023**, *13*, 2103. https://doi.org/10.3390/buildings13082103

Academic Editor: Ning Gu

Received: 24 July 2023
Revised: 14 August 2023
Accepted: 17 August 2023
Published: 20 August 2023

1. Introduction

The Architecture, Engineering, and Construction (AEC) industry is currently an epicenter of digital transformation [1], and a key technology driving this transformation is the Building Information Model (BIM), which digitally represents the physical and functional characteristics of a building [2,3]. The BIM assists decision-making across all stages, from the initial design to demolition, and is utilized to preview the design and safety of construction and derive optimized designs before the commencement of construction work [4]. This process involves many stakeholders, such as owners, designers, architects, engineers, etc., who view the construction process from various perspectives and differing opinions, highlighting the need to reach a shared understanding among all parties during building design [5]. BIM software provides functions that enhance collaboration, coordination, and communication among these stakeholders, facilitating the complex design review process [6]. Despite these advantages, communication problems among stakeholders with diverse backgrounds, views, preferences, and levels of expertise cause limitations to the adoption and implementation of BIM [7]. To overcome these limitations, the AEC industry requires practical tools and methods to bolster stakeholders' spatial cognition and comprehension. Consequently, Augmented Reality (AR) and Virtual Reality (VR) are emerging as promising solutions. By endowing 3D models with a sense of reality, AR/VR can help stakeholders feel as though they are inside the virtual space, thereby promoting an intuitive understanding of the design [8]. The characteristics of these technologies suggest that their integration with BIM could further enhance stakeholders' spatial awareness and comprehension, and related research is actively underway.

Bhoir and Esmaeili [9] conducted a literature review and interviews with 41 OSHA education centers, involving nine safety education officers and 15 experts, to gauge the utilization and potential of VR in US construction safety training. Their findings revealed that most centers employed conventional teaching methods, and a mere 7% considered using VR in the upcoming two years. Significant barriers were the lack of computer literacy among construction workers and the deficit of skills to develop VR environments.

Delgado et al. [10] conducted mixed-method research, surveying 54 construction professionals to identify factors influencing AR and VR adoption in construction. Although VR/AR could enhance construction productivity, their uptake remains low. The most compelling reason for adoption was for improved project delivery. However, the technologies were seen as costly and immature for construction purposes.

Noghabaei et al. [11] assessed the status and growth prospects of AR/VR in the AEC sector based on two online surveys conducted over a year, targeting 158 AEC professionals. Results indicated a predicted rise in AR/VR use within the next 5–10 years. However, budget constraints and a limited understanding of the technology were cited as significant impediments.

Dashti and Viljevac-Vasquez [12] interviewed 13 individuals from the Swedish construction sector to discern digitalization trends, focusing on VR. The study found that integrating BIM with AR/VR offers potential benefits. However, AR/VR technologies are deemed technically immature for broad usage in Sweden's construction industry.

Ghobadi and Sepasgozar [13] studied VR's adaptability in construction by reviewing the literature and interviewing 15 participants from two universities. Their research underscored VR's potential to enhance construction productivity. However, economic considerations, high-end computer requirements, and accessibility issues remain deterrents.

Badamasi et al. [14] surveyed 250 UK AEC professionals, securing 123 responses, to understand VR's application in construction. Results showed that VR could significantly elevate safety, quality, and productivity for the industry. Nevertheless, barriers included insufficient technological know-how, initial costs, and complexities in application development.

However, using such VR equipment has many drawbacks; multiple people cannot use it simultaneously, and there are limitations when looking at the exact location while conversing. This is particularly important in the construction sector where exchanging ideas and having conversations with stakeholders is crucial to extract optimized design, and design review using VR is very vulnerable [15]. To solve these problems, the concept of the Cave Automatic Virtual Environment (CAVE) was introduced. The CAVE system, developed in 1972 by the Electronic Visualization Laboratory (EVL) at the University of Illinois in Chicago, is a technology that allows multiple users to simultaneously experience the same virtual environment. Cruz-Neira et al. [16] proved the connection between actual senses and screen size but found the original CAVE system unsuitable for handling BIM data.

To address these limitations, Nseir [17] first developed BIM CAVE, which applies the CAVE system to BIM, allowing users to feel a sense of presence while displaying a 3D model using BIM software. Since then, various studies have been conducted to enhance the BIM CAVE system. Subramanian [18] developed a BIM CAVE application and updated it to include a top view, enabling inspection of the interrelationships of multiple mechanical, electrical, and plumbing (MEP) elements. In addition, Kuncham [19] added a feature to visually display the construction sequence through a timeline instead of a Gantt chart-style construction schedule. With these updated features, project participants could more easily understand the construction schedule and examine each construction phase in detail through BIM. Texas A&M University recognized that the CAVE system was not originally designed to handle BIM data and developed a commercial BIM application-based BIM CAVE system in 2011 that made it unnecessary to convert BIM file formats [17]. However, this BIM CAVE system could only be connected to three computers, limiting the creation of BIM-based immersive virtual environments. To overcome these limitations, Kang et al. [20] updated the BIM CAVE application to enable the synchronization of nine computers. This provided a fully immersive virtual environment, improving communication among stakeholders. As virtual technology advances, it is crucial to delve into the academic backdrop and prior studies on spatial cognition, especially within the evolving realm of virtual environments.

2. Literature Review

Lawton [21] explored gender differences in wayfinding strategies. A survey on the wayfinding strategies used by males and females was conducted, and the results were analyzed using Oblique factor analysis. The analysis revealed that women tend to use route strategies more, while men lean more toward cardinal direction strategies. A positive correlation existed between cardinal direction strategies and spatial perception ability. However, a limitation of this study was the failure to consider various variables such as age groups and cultural backgrounds.

Saucier et al. [22] conducted an experiment to understand gender differences in spatial navigation capabilities. The experimental method had participants follow navigation instructions based on landmarks or Euclidean cues. Results showed that males performed best when using Euclidean information, while females excelled with landmark information. A limitation of this study exclusively involved university students, limiting its general applicability.

Parsons et al. [23] investigated gender differences in mental rotation and spatial rotation in virtual environments. To this end, the research examined the mental rotation test (MRT) in its traditional paper-and-pencil version and rotational abilities in a virtual setting among 44 adults. The results replicated the gender differences traditionally observed in the paper-and-pencil test, but no gender differences were observed in the virtual environment. The outcome offers intriguing insights into task requirements and the role of motor engagement. The limitations of this study include its small sample size, recruitment exclusively from the U.S., and the lack of consideration of diverse causal relationships regarding gender differences.

Feng et al. [24] aimed to compare gender differences in spatial cognition, conducting an experiment with 124 university students. The experimental group played action video games for 10 h, while the control group did not. Two tests were conducted: the first measured spatial selective attention, and the second assessed mental rotation abilities. Results showed that the experimental group experienced a significant enhancement in spatial cognition, with female participants showing even greater improvement than their male counterparts. However, there was no improvement in the control group. A limitation of this study is the small size of both the experimental and control groups, restricting the generalizability of the findings.

Moffat [25] investigated the relationship between aging and spatial navigation ability through experiments using virtual environments. Virtual environments allow researchers to control visual features and complexity, precisely record behavioral responses, and manipulate paths. Therefore, using a virtual environment is a familiar method in studies related to spatial navigation ability. The results indicated that older adults face greater difficulties in spatial navigation ability than younger adults, suggesting that age influences spatial abilities. However, the author emphasized the limitation that an ongoing discussion revolves around the degree to which research utilizing virtual environments is contingent upon behaviors and neural mechanisms that replicate real-world navigation.

Sorby [26] pursued research to enhance 3D spatial skills. To this end, a course aimed at improving 3D spatial skills was offered to incoming students. The study found that such a course had a positive impact, especially on the success of female students. However, a limitation is that the course might only be applicable to specific schools or departments.

Salthouse [27] explored how human cognitive abilities change with age. The study selectively reviewed previous studies, analyzing cognitive ability measurement tools used in various contexts from these studies, and investigated the relationship between aging and cognitive ability. The results identified a negative impact of aging on cognitive ability. However, a limitation shows that previous studies are often selectively sampled by excluding seniors with health issues or diagnosed diseases.

Klencklen et al. [28] provided a comprehensive overview of recent findings on the changes in spatial cognitive ability among older individuals. The research was to explore interventions and strategies to maintain and enhance the spatial cognitive abilities of older individuals. The study compared tasks used in animal and human studies and a meta-analysis to verify the effects of interventions and strategies. The results suggest that interventions combining physical and cognitive activities can help maintain spatial cognitive abilities in the elderly. However, some findings were contradictory or inconsistent, and the tasks used in human studies may differ from those in animal studies, limiting the generalization of results. Furthermore, they suggested that such interventions and strategies might not apply to all older adults, as their effectiveness can vary depending on an individual's health status and cognitive ability level.

Green and Bavelier [29] explored the influence of action video games on learning and attention. The study conducted a comparison between a group that actively played action video games and a control group that did not engage in such activity. Results indicated that those who played action video games exhibited significant improvements in cognitive abilities, evident across various domains like field of view, spatial cognition, reaction time, and attention focus. This study is limited by the predominance of college students in the participant pool, prompting inquiries into the broader relevance of the conclusions.

Wiener et al. [30] conducted research to understand how age affects wayfinding strategies and how this influences successful performance. Participants' performance using same-direction trials was tested to verify whether participants successfully learned routes. During route learning, the older participant group exhibited particular challenges when approaching intersections from unfamiliar directions. Also, in same-direction trials, younger participants outperformed older ones, concluding that younger individuals are generally more successful in wayfinding. A limitation of this study is the difficulty in aligning laboratory findings with real-world wayfinding.

Cheng and Mix [31] investigated the impact of mental rotation training on math performance. Employing a pretest–posttest control group design, they conducted the training with 120 children aged 6–8, splitting them into experimental and control groups. The findings indicated a substantial enhancement in mathematical problem-solving abilities within the spatial training group, in contrast to the control group. However, it is noteworthy that this study's scope was confined exclusively to children aged 6–8, thereby imposing limitations on the extent to which its conclusions can be generalized.

Uttal et al. [32] sought to understand the malleability of spatial skills and conducted a meta-analysis of training studies. For this purpose, the authors analyzed 217 studies investigating the efficacy of training in improving spatial skills, the magnitude of the effect, its persistence, and its potential for generalization. The study used Hedges' g to measure the effect size. The results indicated that training is effective in enhancing spatial skills, and this enhancement is both persistent and generalizable to other spatial tasks. Additionally, moderators such as the control group, gender, age, and training methods were analyzed. A limitation of this study is the considerable variance among the studies and an insufficient comparison between different training methods. The methods, advantages, disadvantages, applications, and research gaps within these studies are summarized in Table 1.

Table 1. Summary of literature review.

Type	Authors	Methods	Advantages	Disadvantages	Applications	Research Gap
Age	Moffat [25]	Virtual environments for examining aging and spatial navigation	Precise recording, controlled environment	Limited real-world applicability	Understanding age-related changes in spatial navigation	While based on prior research, actual experiments were not conducted
	Salthouse [27]	Review of studies analyzing aging and cognitive ability	Wide array of cognitive measurement tools	Selective sampling excluding certain seniors	Understanding age-related changes in cognitive abilities	Did not address real test results
	Klencklen et al. [28]	Meta-analysis on spatial cognitive ability in elderly	Comprehensive review of interventions	Human and animal studies can have different tasks	Strategies for spatial cognition in elderly	Lacked experiments and research involving diverse age groups
	Wiener et al. [30]	Testing wayfinding strategies in different age groups	Direct observation of wayfinding behaviors	Difficult alignment with real-world wayfinding	Insights into age-related wayfinding strategies	Strategies for spatial cognition in elderly
Gender	Lawton [21]	Survey on gender-specific wayfinding strategies	Identification of gender-specific strategies	Failed to consider age groups and cultural backgrounds	Insights into gender-specific wayfinding tendencies	Various age groups were not taken into consideration
	Saucier et al. [22]	Navigation instructions based on landmarks or cues	Direct measure of navigation strategies	Limited to university students	Understanding gendered preferences in spatial navigation	No research based on various demographic characteristics
	Parsons et al. [23]	Mental rotation tests in traditional and virtual setups	Examination in both traditional and digital settings	Small sample size and lack of diverse causal consideration	Exploring gender differences in mental and spatial rotation	Did not consider participants' diverse backgrounds (job, education)
Education	Sorby [26]	Course on enhancing 3D spatial skills for students	Direct educational intervention	Applicability limited to specific institutions	Educational strategies to enhance spatial skills	Only targeted majors, not considering diverse occupational characteristics
	Cheng & Mix [31]	Mental rotation training on math performance in children	Direct impact assessment on math skills	Age-limited sample	Application of spatial training in enhancing math skills	Did not account for variations in adults' virtual environment experiences

Table 1. *Cont.*

Type	Authors	Methods	Advantages	Disadvantages	Applications	Research Gap
Education	Uttal et al. [32]	Meta-analysis of 217 training studies	Demonstrated malleability of spatial skills, persistence, and generalizability of training effects.	Significant variance across studies; insufficient comparison between different training methods.	Training's impact on spatial skills.	No actual experiments conducted; individual characteristics not considered
Game	Feng et al. [24]	Experiments with action video games on university students	Direct comparison with a control group	Small experimental and control groups	Enhancement of spatial cognitive ability after game exposure	Insufficient data used in the experiment, making generalization difficult
	Green & Bavelier [28]	Comparison study using action video games	Wide range of cognitive ability measures	Predominantly college student participants	Effects of action video games on cognitive abilities	Focused on a specific age group, did not consider diverse age factors

As corroborated by prior research, virtual environments in the AEC industry have emerged as essential instruments for augmenting communication among project stakeholders and bolstering the visual comprehension of projects. In contrast to most preceding investigations conducted in more generalized contexts, this study uniquely centers on spatial cognitive abilities within the specialized framework of the BIM CAVE system. The BIM CAVE system has been innovatively designed to escalate this comprehension by providing a sophisticated virtual environment. Its evolution has been marked by the goal of improving stakeholder communication through a thoroughly immersive virtual experience. However, the efficacy of the BIM CAVE system does not rely only on its technical features but is significantly impacted by the spatial cognition skills of the stakeholders utilizing this technology. In particular, a stakeholder's ability to perceive and understand spatial constructs within a virtual environment can exhibit substantial variance based on individual characteristics, such as age, gender, education level, and gaming experience [33–36]. These individual traits can profoundly influence spatial perception via the BIM CAVE, and elucidating their impacts is crucial for optimizing and maximizing the utility of this technology. Consequently, this research aims to explore how a stakeholder's characteristics, such as age, gender, educational background, and gaming experience, influence their spatial perception and understanding in a BIM-enabled virtual environment within the AEC industry. Unlike previous studies, this research uniquely measures and analyzes the finer aspects of spatial cognition based on participants' direct experiences in the BIM CAVE environment, emphasizing the direct experiences of participants with diverse characteristics in a virtual environment. To achieve this, statistical methods were employed to analyze the data gleaned from surveys, aiming to understand the impact of individual traits on spatial perception.

3. Research Methodology

This study conducted a survey to determine the impact of various variables, such as age, gender, education, and gaming experience, on spatial cognition and understanding in a virtual environment. Given that the survey was conducted with human subjects, it was performed under the approval (KNUIRB 2022-01-005-002) of the Institutional Review Board of Kangwon National University to protect the rights and safety of the research participants, following bioethics. Following the survey and sampling process, a statistical analysis was carried out.

The survey used in this study consisted of a preliminary survey, which included questions about the participants' personal information, and a post-experience survey, which posed questions about how participants perceived space in the virtual environment after the experience. The details are as follows:

- Preliminary Survey: A preliminary survey was conducted to understand participants' personal information and previous virtual environment experiences. Questions regarding age, gender, knowledge level acquired through BIM or 3D modeling-related education, and experiences using games or VR devices were presented. This demographic information was used to comprehend the participants' backgrounds and identify which variables could influence their understanding and interpretation of virtual environments;
- Post-Experience Survey: A post-experience study was conducted after participants had directly experienced the BIM multi-display virtual environment. In the post-experience survey, questions were posed to understand how participants evaluated their spatial cognition in the virtual environment. Specifically, they were asked: 'How many sprinklers did you find in the experiment?', 'Do you think the virtual environment is realistic?', and 'How would you rate the realism of the virtual environment?'. The focus was to collect feedback on participants' spatial cognition and understanding and aimed to understand how participants evaluated their spatial cognition and realism in the virtual environment. A 5-point Likert scale was employed, rating the level of realism in the virtual environment they felt as 'not real at all', 'somewhat unreal', 'average', 'somewhat real', or 'very real'.

In the data analysis stage, the Kruskal–Wallis one-way test and Mann–Whitney U test were utilized. The Kruskal–Wallis one-way test is a nonparametric method that tests whether the means of three or more independent groups are the same [37], while the Mann–Whitney U test is a method that tests the difference between two groups for non-normally distributed data [38]. Each statistical analysis was used to evaluate the impact of various variables, such as age, gender, education level, and gaming experience, on spatial cognition and understanding in a virtual environment. By performing these analyses, it can be determined how these variables affect spatial perception and understanding in a virtual environment.

4. Experiment Materials and Method

4.1. Hypothesis Formulation

The objective of this study is to examine the influence of four factors on spatial cognition in a virtual environment: gender, age, education, and gaming experience. To achieve this, the following hypotheses were established.

- Age Hypothesis: Age may influence adaptability to new technology and comprehension of virtual environments. The younger generation, being digital natives, may better understand new technologies, such as virtual environments. Therefore, participants in younger age brackets are expected to demonstrate higher spatial cognition;
- Gender Hypothesis: From scientific research and empirical evidence, it has generally been demonstrated that males show higher spatial cognition than females. Such differences often relate to structural variances in the brain and differences in testosterone levels. Therefore, it is hypothesized that male participants will exhibit more spatial cognition in a 3D virtual environment than their female counterparts;
- Education Hypothesis: Education significantly influences an individual's information processing, problem-solving, and analytical abilities. These skills are directly correlated with spatial cognition in a virtual environment. Therefore, it is hypothesized that participants with a higher level of education will display stronger spatial cognition in a virtual environment;

- Gaming Experience Hypothesis: Experiences with VR and simulation games can enhance comprehension and spatial cognition in virtual environments. Gaming is particularly effective in enhancing the ability to navigate and understand complex spaces. Therefore, participants with extensive experience in such games are expected to exhibit higher spatial cognition in a 3D virtual environment.

4.2. Survey Design

This study established a BIM CAVE multi-display environment to measure participants' spatial perception abilities using an experiential survey, as illustrated in Figure 1. Spatial perception is a cognitive function primarily managed by the right brain, relating to the processing of visual shapes and patterns [39]. Accordingly, Allen [40] classified spatial perception abilities into three components: object recognition, spatial location awareness, and user orientation sense, representing scenarios where a stationary observer recognizes a stationary object, a fixed or moving observer recognizes a moving object, and a moving observer recognizes a fixed object, respectively.

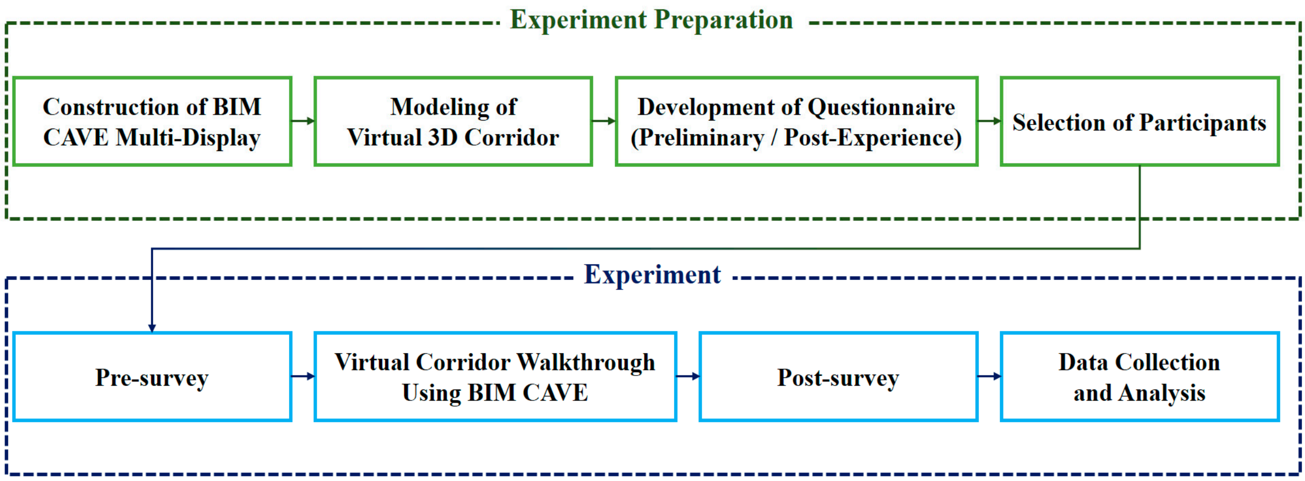

Figure 1. Flow chart of the experiment design.

Here, user orientation sense among elements classified in previous studies is emphasized to observe differences in spatial perception abilities depending on the participant's gender, age, education level, and gaming experience. As shown in Figure 2, a 3D virtual corridor model inclusive of corners was produced using Autodesk Revit. Additional 3D modeling was performed to incorporate essential components of the corridor, such as floors, walls, doors, ceilings, and piping. They were strategically placed at random positions throughout the corridor to prevent participants from anticipating and counting the sprinklers. Upon completion of the corridor model, it was then converted into a Navisworks file, facilitating the construction of the 3D virtual corridor environment. Participants navigated the virtual corridor model using a controller facilitated by the navigation feature in Autodesk Navisworks.

A BIM CAVE multi-display environment was set up with one display per computer, and a total of five screens were positioned at a 45° angle to allow users to be surrounded by 180° of screens, as shown in Figure 3. Participants performed the task of counting the number of sprinklers while moving through the corridor. The sprinklers were installed on the ceiling of the virtual corridor model, as depicted in Figure 4, with 23 sprinklers positioned. This study used the accuracy with which the moving participants identified the number of stationary sprinklers to measure authenticity. This served as evidence to evaluate the diligence participants demonstrated in their engagement with the survey.

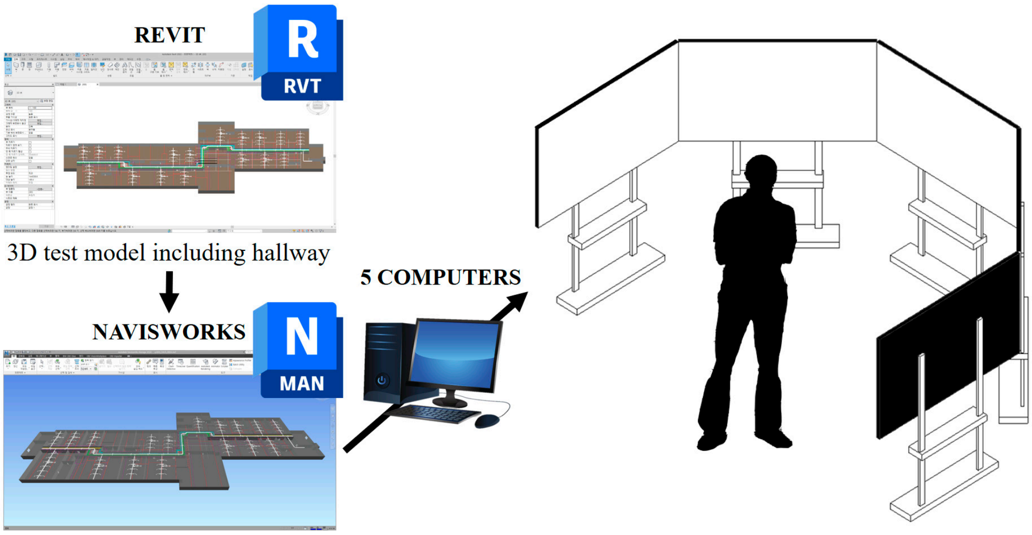

Figure 2. Setup of the virtual environment using the BIM CAVE application.

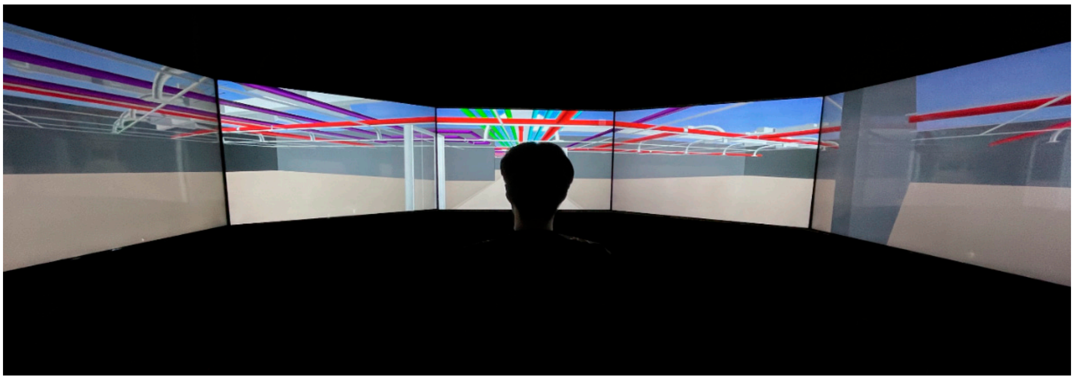

Figure 3. Survey scene in the virtual environment using BIM.

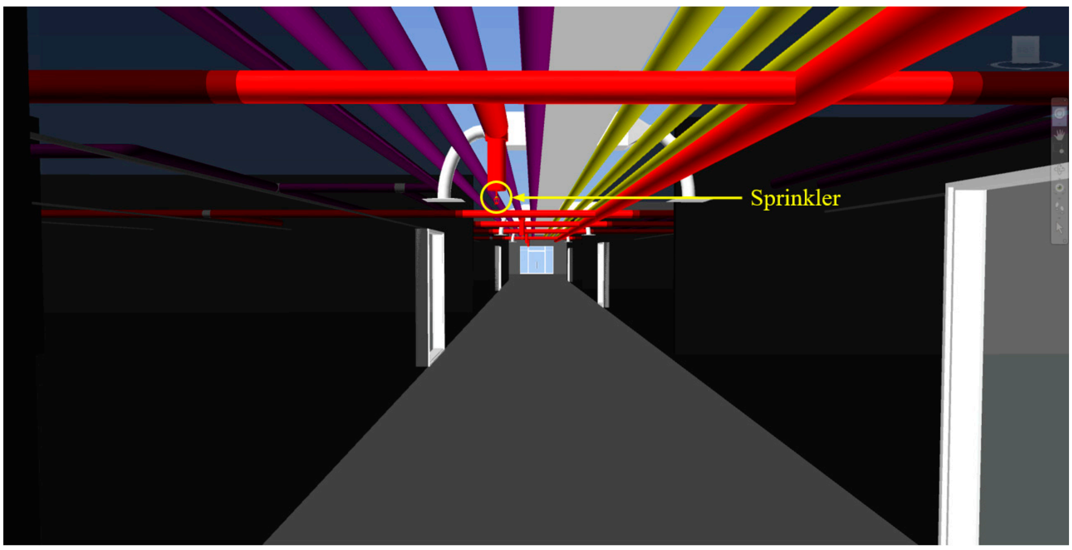

Figure 4. A 3D virtual corridor model with sprinklers.

During the survey participant selection process, the aim was to minimize biases and reflect diverse user experiences. This decision involved considering a balanced proportion of various ages and genders, ensuring no specific age group was dominated by one gender. Notably, students from major and non-major courses of study, professionals from design fields, and individuals from other professions were included within each age group.

The survey was conducted for two months, from 1 July 2022 to 31 August 2022, with 76 completed surveys obtained. From the 76 survey responses received, 30 were chosen for analysis based on two main criteria, completeness and reliability, to ensure statistical validity. 'Completeness' was set as a criterion to determine if all survey sections were adequately answered. Considering the content and structure of the survey, only responses that covered every question were chosen for the analysis, ensuring data integrity and preventing distortions due to missing data. 'Reliability' was viewed as a measure to evaluate the sincerity and consistency of the respondents. The reliability of survey responses was ensured by assessing the coherence of answers to each question. Notably, when evaluating the content and logicality of each response, any survey with contradictory answers were excluded from the analysis. The sample chosen through this process comprised participants of diverse ages, genders, knowledge, and experience.

4.3. Data Analysis

To analyze significant differences between groups, parametric and nonparametric tests were used. Parametric testing assumes that data follow a specific distribution, including analysis methods such as t-tests and ANOVA. It is primarily used to test differences in group means for continuous data that follow a normal distribution.

In contrast, nonparametric testing is used when data do not follow a specific distribution or when assuming data distribution is challenging. Nonparametric tests have the advantage of not being limited by specific distribution assumptions, with typical methods including the Mann–Whitney U test and the Kruskal–Wallis test. This method is beneficial in comparing medians of ordinal data, such as ranks [41]. When considering the current study, participants' unique characteristics, specifically age, gender, education, and gaming experience, were set as control variables. Given these conditions, the Mann–Whitney U test and the Kruskal–Wallis test methods were employed to determine if the differences in spatial perception ability based on these characteristics were statistically significant.

In this study, the measure of reality in a virtual environment constitutes ordinal data, with the median value being the primary interest of investigation. As such, the measure of reality in the virtual environment was designated as a variable of interest, and we performed a non-parametric test to examine whether the differences in spatial cognitive ability based on participants' characteristics were statistically significant. The measured value (variables of interest) of each experimental hypothesis, variables, and the utilized testing methods are summarized in Table 2.

Table 2. Variables and their statistical test methods.

No.	Variable	Statistical Test Method
1	Age	Kruskal–Wallis one-way
2	Gender	Mann–Whitney U test
3	Education	Mann–Whitney U test
4	Gaming experience	Mann–Whitney U test

In all tests, an alpha level of 5% ($p = 0.05$) was used to determine significance. An alpha level of 5% is a widely used standard in human–computer interaction [42]. Furthermore, all tests were conducted using the Statsmodel library [43] and the Scipy library [44] in a Python Jupyter Notebook environment.

5. Results and Discussion

5.1. Survey Participants

To test the hypotheses, a total of 30 survey responses were analyzed. Efforts were made to recruit balanced participants, considering demographic information such as age and gender, prior participation in BIM or 3D modeling-related education, and experience with games or VR devices. However, the relationship between educational participation and age was inevitably correlated. Table 3 presents the demographic statistics of the experiment participants.

Table 3. Demographics of the experiment participants.

Variables	Category	Population
Age	20–24	5
	25–34	6
	35–44	12
	Over 45	7
Gender	Male	14
	Female	16
Education	Yes	6
	No	24
Gaming experience	Yes	22
	No	8

5.2. Differences in Spatial Perception Based on Personal Characteristics of Survey Participants

The aim was to measure the spatial perception and understanding of the users by testing for differences in the perception of realism in the virtual environment among specific variables or groups, including age, gender, and educational background, during the participants' engagement in the experiment. A post-experience question was posed to assess the users' spatial perception and the realism of the virtual environment after the experience: "How would you rate the realism of the virtual environment?" Participants responded to the realism of the virtual environment level on a 5-point Likert scale, with options including 'not real at all', 'somewhat unreal', 'average', 'somewhat real', and 'very real'.

5.2.1. Age Range

A multiple-choice question related to age was placed in the preliminary survey to ascertain the participants' age groups. Participants were classified into four subgroups: '20–24 years', '25–34 years', '35–44 years', and '45 years and over', with 17%, 20%, 40%, and 23% of participants in each respective group. Figure 5 depicts the participation rate by age group, showing that 40% of the participants were '35–44 years': the largest proportion of participants.

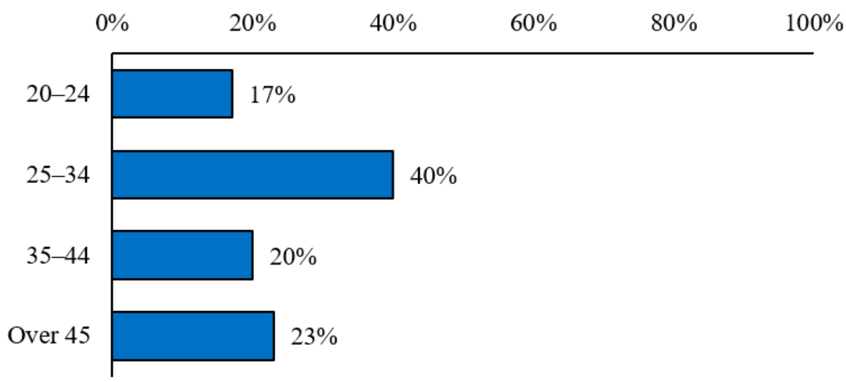

Figure 5. Survey results of age group.

The hypothesis set in this study regarding age predicted that the younger generation would show higher spatial perception ability due to a superior understanding of new technologies. As age consists of more than three groups, unlike other variables, the effect of age on spatial perception abilities was investigated using the Kruskal-Wallis one-way test. The results showed a statistical value of 1.95 and a *p*-value of 0.38, indicating that the difference in spatial perception abilities between age groups was not statistically significant.

This result contrasts with the findings of Moffat [25], which reported that aging relates to impairments in spatial navigation and navigational abilities. Similarly, Klencklen et al. [28] reported that as age increases, spatial navigation performance decreases due to impairment of spatial memory, a finding similarly suggested by Wiener et al. [30]. However, the results are consistent with the recent research outcomes of Salthouse [27], which failed to find a strong correlation between age and spatial cognitive ability. Salthouse's [27] research discusses an array of factors that might contribute to changes in cognitive abilities, underlining the importance of considering individual variances, as not everyone experiences the same declines in cognitive skills with age.

5.2.2. Gender

To ascertain the participants' genders, a multiple-choice question related to gender was placed in the preliminary survey. Participants were classified into two subgroups: 'male' (47%) and 'female' (53%), as depicted in Figure 6. This gender classification provided important information for analyzing the impact of gender on spatial perception abilities in a virtual environment.

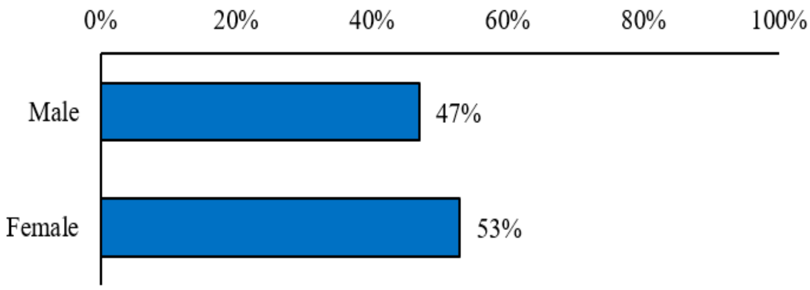

Figure 6. Survey results of gender.

The hypothesis for gender predicted that men would have a higher spatial perception ability in the 3D virtual environment than women, given the biological differences in men's spatial perception abilities. However, testing the effect of gender on spatial perception abilities using the Mann–Whitney U test resulted in a statistical value of 107 and a *p*-value of 0.85. This shows that gender does not have a significant impact on spatial perception abilities, contrary to the study by Lawton [21], which argues that men have superior spatial perception abilities.

Conversely, the results align with the research of Saucier et al. [22] and Parsons et al. [23]. These studies concluded that there were no significant differences in spatial perception abilities by gender, suggesting that gender is not a decisive factor. In particular, Parsons et al. [23] reported that while some gender differences occurred in 2D environments, there were no effects of gender in virtual environments, which supports the findings of the study.

5.2.3. Education

A relevant multiple-choice question was placed in the preliminary survey to ascertain whether the participants had attended any BIM or 3D modeling-related education. Participants were classified into two subgroups: 'yes' and 'no'. According to the responses, only 20% of all participants had experienced BIM or 3D modeling-related education. The majority, 80% of the participants, did not have such educational experience. The education participation appeared closely related to the participant's age. The low percentage of those who received education is likely due to reduced education accessibility among older participants, as clearly seen in Figure 7.

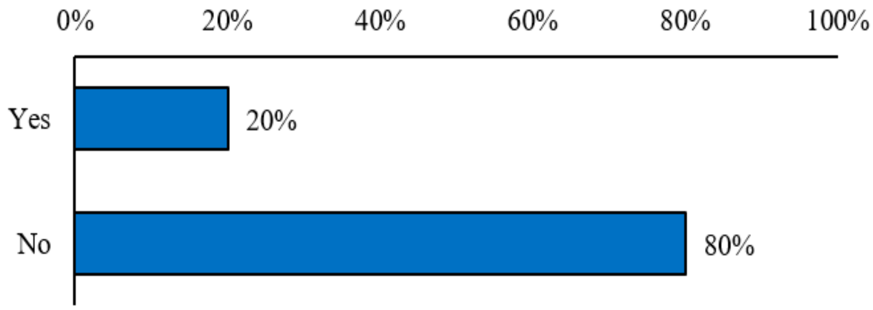

Figure 7. Survey results of education.

The hypothesis regarding the level of education predicted that participants with a higher education level would have superior spatial perception abilities in the virtual environment. However, testing the effect of the level of education on spatial perception abilities using the Mann–Whitney U test resulted in a statistical value of 86 and a *p*-value of 0.48. This shows that the level of education did not have a significant impact on spatial perception abilities, contrasting with the research findings of Cheng and Mix [31] and Sorby [26], which argue that level of education is a crucial factor affecting spatial perception abilities. Particularly, Sorby [26] asserted that students' 3D spatial visualization skills significantly improved through an engineering graphics course, suggesting that education can enhance spatial abilities.

However, the findings align with the research of Uttal et al. [32] which emphasize that spatial skills are markedly malleable and can be enhanced through training and experience, irrespective of an individual's level of education. Therefore, the research provides evidence that education itself does not significantly influence spatial perception abilities.

5.2.4. Gaming Experience

A related multiple-choice question was placed in the preliminary survey to ascertain whether participants had experience using games or VR devices. Participants were classified into two subgroups: 'yes' and 'no'. Figure 8 shows the proportion of participants according to their experience with games or VR devices. As evident from the figure, the majority, 73% of participants, confirmed having experience with games or VR devices, while 27% of participants did not have such experience.

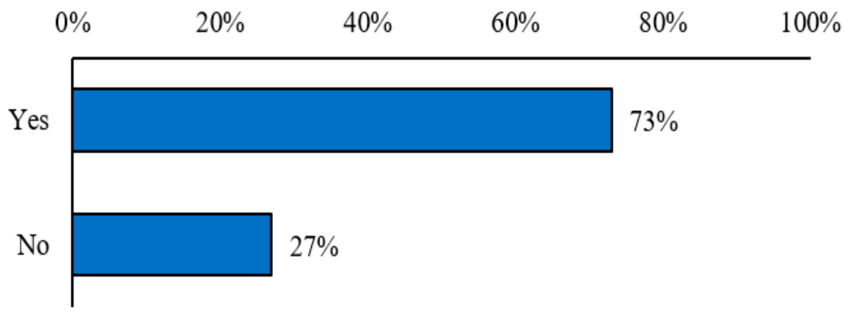

Figure 8. Survey results of game experience.

The hypothesis regarding gaming experience predicted that experience with VR and simulation games would enhance spatial perception abilities. Gaming experience turned out to be the only factor among those studied that significantly impacted spatial perception abilities. The Mann–Whitney U test showed a statistical value of 41 and a *p*-value of 0.03. This confirms that participants with more gaming experience showed enhanced spatial abilities.

These results align closely with the findings of Feng et al. [24] and Green & Bavelier [28], which demonstrated that video game experience is an important factor in enhancing spatial perception abilities. The study by Green & Bavelier [28] found that video games improved participants' spatial perception abilities, attention span, and visual reaction speed. Feng et al. [24] also reported that game experience in a 3D environment improved spatial perception abilities and orientation skills. These results suggest that the complex 3D environment provided by games significantly contributes to training spatial perception abilities. Furthermore, they indicate that video games could also help improve other cognitive abilities, such as visual observation, reaction speed, and multitasking skills, in addition to enhancing spatial perception abilities.

Along with previous research, the findings prove that video game experience can influence spatial perception abilities. Video games can be a potent tool proposed to improve spatial perception abilities. This research could prompt a reevaluation of the value of VR and simulation games as educational or training tools. The immersive environment of games can provide a very effective platform for training participants' spatial perception abilities.

This study investigated and analyzed various factors that affect spatial perception abilities in a virtual environment. Age, gender, and education did not significantly impact spatial perception abilities in the virtual environment; however, the presence or absence of gaming experience significantly affected spatial perception abilities. Participants with gaming experience tended to perceive space in the virtual environment more realistically, indicating a significant correlation between gaming experience and spatial perception abilities. These research results provide important insights for improving spatial perception abilities in a virtual environment.

Generally, age, gender, and education level have been regarded as significant influences on cognitive abilities [45]. However, this study confirms that gaming experience has a more significant impact on spatial perception abilities than these traditional factors, demonstrating that video games are emerging as important tools that can open new possibilities in education and training and can thus be one method of improving spatial perception abilities in a virtual environment. The heightened spatial perception abilities observed in participants with gaming experience in virtual environments can likely be attributed to variations in perceptual capabilities developed through their experiences. Sensation refers to a body's ability to detect external stimuli, such as visual or auditory cues. Perception, conversely, represents the process by which the brain processes and comprehends this sensory information [46]. Virtual environments, mirroring gaming settings, are predominantly graphic-based. Thus, participants familiar with gaming might swiftly recognize and adapt to such graphic-centric surroundings. It is suggested that perceptual skills, honed through gaming experiences, contribute to a more precise understanding and grasp of spatial information within virtual settings. Therefore, it is anticipated that participants with extensive gaming backgrounds would demonstrate enhanced spatial perception abilities in virtual environments.

The findings of this study align to some extent with existing theories in cognitive psychology and virtual environment research, while also offering some contradictions. While it is known that factors like age, gender, and education level can influence cognitive abilities, this study suggests that their impact on spatial awareness in virtual environments might be less significant than previously believed. Instead, contemporary experiences like gaming appear to have a significant influence, suggesting a need to re-evaluate current theories. A significant discovery in this study is that researchers should think beyond traditional notions such as age, gender, and education, when considering the factors that affect cognitive abilities. Instead of only considering traditional factors, it is necessary to deeply consider how modern technologies and experiences affect human cognitive abilities. This approach is expected to provide a broader and more accurate understanding of human cognitive abilities.

6. Conclusions

This study conducted a survey and statistical analysis to assess the impact of the factors of age, gender, education level, and gaming experience on spatial perception ability. A BIM CAVE system was constructed to measure participants' spatial perception abilities using an experiential survey to address this objective. Participants navigated a virtual corridor modeled through Autodesk Revit and were given the task of counting the number of sprinklers. Spatial perception ability was assessed by observing how accurately participants, while in motion, identified the count of stationary sprinklers and navigated their path. After the experience, questions regarding the realism of the virtual environment were posed, and the responses were subsequently analyzed using the Kruskal–Wallis one-way and Mann–Whitney U tests. The results showed that age, gender, and education did not significantly influence spatial perception. However, gaming experience substantially impacted spatial perception ability, suggesting that gaming could significantly enhance spatial understanding.

Nevertheless, this study has two primary limitations. Firstly, the range of age analysis was restricted up to 50, thereby not offering a comprehensive understanding of spatial perception ability in older age groups. Secondly, considering the inequality of educational opportunities, access to BIM or 3D modeling-related education might have been challenging for certain age groups. This could mean that the effect of education on spatial perception ability may not have been entirely reflected in the study. These limitations imply that future research should consider a broader age range and reflect the equality of educational opportunities.

Despite these limitations, the results of this study contribute original insights into understanding how personal characteristics influence spatial perception, offering an effective approach to utilizing BIM-based virtual environments in the future. The study proves that gaming positively impacts spatial understanding in virtual environments, implying that gaming could be an effective educational method for enhancing the ability to navigate and understand complex spaces. This understanding could pave the way for facilitating effective communication and collaboration among stakeholders.

In other words, it can help researchers to understand how spatial perception in virtual environments changes depending on individual characteristics, not merely considering the technical aspects of using virtual environments in the AEC industry. In the AEC industry, the tangible significance of this research lies in improved communication and collaboration among project teams. Stakeholders should strategize to harness the spatial perception abilities of team members with gaming experience to heighten efficiency in design and collaboration within virtual settings. To enhance communication and collaboration based on the insights from this study, stakeholders in the AEC industry are recommended to blend gaming elements or simulators within training modules. This integration can be especially beneficial when introducing new team members to intricate construction projects, augmenting their spatial understanding. It is also pivotal to establish a supportive environment where individuals possessing gaming experience actively guide their peers who might lack such proficiency. This mentorship ensures effective spatial perception within the virtual environment, fostering a deeper comprehension of the virtual environment to determine an optimized design that all the stakeholders are satisfied with before the beginning of the construction phase. Additionally, based on the results of this study, the introduction of game-based educational methods could be contemplated. The research results can facilitate communication among stakeholders with various personal characteristics and provide a basis for collaborative design in virtual environments considering these factors.

As potential directions for future research, studies focusing on spatial perception abilities across a broader age spectrum are essential, along with inquiries exploring the relationship between education levels and spatial perception abilities, considering the equality of educational opportunities. Furthermore, based on the findings of this study, proposals for research into the application methods of virtual environments in the AEC industry and strategies to bolster collaboration are encouraged.

Author Contributions: Conceptualization, J.Y. and B.J.; methodology, J.K.; software, J.K.; validation, C.K. and Y.S.; formal analysis, B.J.; investigation, C.K.; resources, S.K.; data curation, B.J.; writing—original draft preparation, C.K.; writing—review and editing, J.Y.; visualization, C.K.; supervision, J.Y.; project administration, J.Y.; funding acquisition, J.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Research Foundation of Korea (NRF) via a grant funded by the Korean government (MSIT) (No. 2021R1F1A10606851222182102130102).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The IRB-approved number for this study is KNUIRB-2022-01-005-002.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Belle, I. The architecture, engineering and construction industry and blockchain technology. *Digit. Cult.* **2017**, *2017*, 279–284.
2. Wang, L.; Huang, M.; Zhang, X.; Jin, R.; Yang, T. Review of BIM adoption in the higher education of AEC disciplines. *J. Civ. Eng. Educ.* **2020**, *146*, 06020001. [CrossRef]
3. Deke, S. An introduction to building information modeling. *J. Build. Inf. Model.* **2007**, *1*, 12–14.
4. Koppinen, T.; Kiviniemi, A. *Requirements Management and Critical Decision Points*; Working Papers 74; VTT: Espoo, Finland, 2007.
5. Fraser, J.; Chevez, A.; Crawford, J.; Kumar, A.; Froese, T.; Gard, S. *Business Drivers for BIM*; CRC for Construction Innovation: Brisbane, Australia, 2007.
6. Bozoglu, J. Collaboration and coordination learning modules for BIM education. *J. Inf. Technol. Constr.* **2016**, *21*, 152–163.
7. Kassem, M.; Brogden, T.; Dawood, N. BIM and 4D planning: A holistic study of the barriers and drivers to widespread adoption. *J. Constr. Eng. Proj. Manag.* **2012**, *2*, 1–10. [CrossRef]
8. Wang, X.; Love, P.E.; Kim, M.J.; Park, C.-S.; Sing, C.-P.; Hou, L. A conceptual framework for integrating building information modeling with augmented reality. *Autom. Constr.* **2013**, *34*, 37–44. [CrossRef]
9. Bhoir, S.; Esmaeili, B. State-of-the-art review of virtual reality environment applications in construction safety. In *AEI 2015*; American Society of Civil Engineers: Reston, VA, USA, 2015; pp. 457–468. [CrossRef]
10. Delgado, J.M.D.; Oyedele, L.; Demian, P.; Beach, T. A research agenda for augmented and virtual reality in architecture, engineering and construction. *Adv. Eng. Inform.* **2020**, *45*, 101122. [CrossRef]
11. Noghabaei, M.; Heydarian, A.; Balali, V.; Han, K. Trend analysis on adoption of virtual and augmented reality in the architecture, engineering, and construction industry. *Data* **2020**, *5*, 26. [CrossRef]
12. Dashti, B.; Viljevac-Vasquez, R. Exploring Use and Perception of Augmented-and Virtual Reality in the Swedish AEC Industry. Master's Thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2020.
13. Ghobadi, M.; Sepasgozar, S.M. An investigation of virtual reality technology adoption in the construction industry. In *Smart Cities and Construction Technologies*; IntechOpen: London, UK, 2020; pp. 1–35. [CrossRef]
14. Badamasi, A.A.; Aryal, K.R.; Makarfi, U.U.; Dodo, M. Drivers and barriers of virtual reality adoption in UK AEC industry. *Eng. Constr. Archit. Manag.* **2022**, *29*, 1307–1318. [CrossRef]
15. Liu, Y.; Castronovo, F.; Messner, J.; Leicht, R. Evaluating the impact of virtual reality on design review meetings. *J. Comput. Civ. Eng.* **2020**, *34*, 04019045. [CrossRef]
16. Cruz-Neira, C.; Sandin, D.J.; DeFanti, T.A.; Kenyon, R.V.; Hart, J.C. The CAVE: Audio visual experience automatic virtual environment. *Commun. ACM* **1992**, *35*, 64–73. [CrossRef]
17. Nseir, H. Immersive Representation of Building Information Model. Master's Thesis, Texas A & M University, College Station, TX, USA, 16 July 2012.
18. Subramanian, A.G. Immersive Virtual Reality System Using BIM Application with Extended Vertical Field of View. Master's Thesis, Texas A & M University, College Station, TX, USA, 19 October 2012.
19. Kuncham, K. Timelining the Construction in Immersive Virtual Reality System Using BIM Application. Master's Thesis, Texas A & M University, College Station, TX, USA, 17 May 2013.
20. Kang, J.; Yeon, J.; Kandregula, S. Fabrication of BIM CAVE 2: Challenges in Handling 9 Screen Walls. In Proceedings of the 2015 32nd International Symposium on Automation and Robotics in Construction and Mining (ISARC), Oulu, Finland, 15–18 June 2015; pp. 1–5. [CrossRef]
21. Lawton, C.A. Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles* **1994**, *30*, 765–779. [CrossRef]
22. Saucier, D.M.; Green, S.M.; Leason, J.; MacFadden, A.; Bell, S.; Elias, L.J. Are sex differences in navigation caused by sexually dimorphic strategies or by differences in the ability to use the strategies? *Behav. Neurosci.* **2002**, *116*, 403–410. [CrossRef] [PubMed]
23. Parsons, T.D.; Larson, P.; Kratz, K.; Thiebaux, M.; Bluestein, B.; Buckwalter, J.G.; Rizzo, A.A. Sex differences in mental rotation and spatial rotation in a virtual environment. *Neuropsychologia* **2004**, *42*, 555–562. [CrossRef] [PubMed]

24. Feng, J.; Spence, I.; Pratt, J. Playing an action video game reduces gender differences in spatial cognition. *Psychol. Sci.* **2007**, *18*, 850–855. [CrossRef] [PubMed]
25. Moffat, S.D. Aging and spatial navigation: What do we know and where do we go? *Neuropsychol. Rev.* **2009**, *19*, 478–489. [CrossRef]
26. Sorby, S.A. Educational Research in Developing 3-D Spatial Skills for Engineering Students. *Int. J. Sci. Educ.* **2009**, *31*, 459–480. [CrossRef]
27. Salthouse, T.A. Selective review of cognitive aging. *J. Int. Neuropsychol. Soc.* **2010**, *16*, 754–760. [CrossRef]
28. Klencklen, G.; Després, O.; Dufour, A. What do we know about aging and spatial cognition? Reviews and perspectives. *Ageing Res. Rev.* **2012**, *11*, 123–135. [CrossRef]
29. Green, C.S.; Bavelier, D. Learning, attentional control, and action video games. *Curr. Biol.* **2012**, *22*, R197–R206. [CrossRef]
30. Wiener, J.M.; de Condappa, O.; Harris, M.A.; Wolbers, T. Maladaptive bias for extrahippocampal navigation strategies in aging humans. *J. Neurosci.* **2013**, *33*, 6012–6017. [CrossRef] [PubMed]
31. Cheng, Y.L.; Mix, K.S. Spatial training improves children's mathematics ability. *J. Cogn. Dev.* **2014**, *15*, 2–11. [CrossRef]
32. Uttal, D.H.; Meadow, N.G.; Tipton, E.; Hand, L.L.; Alden, A.R.; Warren, C.; Newcombe, N.S. The malleability of spatial skills: A meta-analysis of training studies. *Psychol. Bull.* **2013**, *139*, 352–402. [CrossRef]
33. Salthouse, T.A. Adult age differences in integrative spatial ability. *Psychol. Aging* **1987**, *2*, 254–260. [CrossRef] [PubMed]
34. Weiss, E.M.; Kemmler, G.; Deisenhammer, E.A.; Fleischhacker, W.W.; Delazer, M. Sex differences in cognitive functions. *Personal. Individ. Differ.* **2003**, *35*, 863–875. [CrossRef]
35. Marunic, G.; Glazar, V. Spatial ability through engineering graphics education. *Int. J. Technol. Des. Educ.* **2013**, *23*, 703–715. [CrossRef]
36. McClurg, P.A.; Chaillé, C. Computer games: Environments for developing spatial cognition? *J. Educ. Comput. Res.* **1987**, *3*, 95–111. [CrossRef]
37. Daniel, W.W. Kruskal–Wallis one-way analysis of variance by ranks. In *Applied Nonparametric Statistics*; Cengage Learning: Boston, MA, USA, 1990; pp. 226–234.
38. Mann, H.B.; Whitney, D.R. On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Stat.* **1947**, *18*, 50–60. [CrossRef]
39. MacNeilage, P.F.; Rogers, L.J.; Vallortigara, G. Origins of the left & right brain. *Sci. Am.* **2009**, *301*, 60–67. [CrossRef]
40. Allen, G.L. Functional families of spatial abilities: Poor relations and rich prospects. *Int. J. Test.* **2003**, *3*, 251–262. [CrossRef]
41. Sheskin, D.J. *Handbook of Parametric and Nonparametric Statistical Procedures*; CRC Press: Boca Raton, FL, USA, 2020. [CrossRef]
42. Lazar, J.; Feng, J.H.; Hochheiser, H. *Research Methods in Human-Computer Interaction*; Morgan Kaufmann: Burlington, MA, USA, 2017.
43. Seabold, S.; Perktold, J. Statsmodels: Econometric and statistical modeling with python. In Proceedings of the 9th Python in Science Conference(SciPy), Austin, TX, USA, 28 June–3 July 2010; pp. 92–96. [CrossRef]
44. Virtanen, P.; Gommers, R.; Oliphant, T.E.; Haberland, M.; Reddy, T.; Cournapeau, D.; Burovski, E.; Peterson, P.; Weckesser, W.; Bright, J. SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nat. Methods* **2020**, *17*, 261–272. [CrossRef] [PubMed]
45. Cattell, R.B. *Abilities: Their Structure, Growth, and Action*; Houghton Mifflin: Boston, MA, USA, 1971; pp. 130–167.
46. Goldstein, E.B. *Sensation and Perception*, 8th ed.; Cengage Learning: Belmont, CA, USA, 2021; pp. 5–67.