ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0621
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

A Framework for Assessing the Learning Performance and Creativity in Spatial Features by Immersive Virtual Environments

Jae-ho Jang[1], Jin-bin Im[1]*, En-Lian Zhang[1], Moon-boo Joo[1], Shin-Hyun Kang[1] and Ju-Hyung Kim[1]*

[1] *Department of Architectural Engineering, Hanyang University, Seoul 04763, South Korea,* E-mail address: 0404mm@naver.com, jbim0202@hanyang.ac.kr, eunryeon@hanyang.ac.kr, joomb2000@hanyang.ac.kr, shinhuny@naver.com, kcr97jhk@hanyang.ac.kr

Abstract: The development of immersive virtual environment (IVE) technologies has allowed for virtual simulations and exploration of architectural spaces before building the facilities. Although various researchers have implemented IVEs to demonstrate their effectiveness, these rigorous methods for evaluation have obtained little attention. For education facilities, learning environments are crucial factors influencing students' academic performance and attention. Previous studies have evaluated the capabilities of spaces in terms of the learning performance of students in actual conditions. However, various spatial features cannot be experienced in real-world situations despite the introduction of IVEs that can validate the learning performance. This study aims to propose a framework to compare learning abilities in real space and identical ones implemented by two different methods: Virtual Reality and Mixed Reality. To this end, various cognitive and creativity tests are conducted i.e., N-back, Go/No-go, Spatial working memory updating, and Torrance Test of Creative Thinking-verbal tests. Then, a comparison is conducted to show cognition and creativity between real and virtual experiences.

Key words: education facilities, virtual environments, spatial features, cognition, learning performance

1. INTRODUCTION

Thoring et al. [1] have highlighted the impact of spatial configuration on work efficiency and learning performance that led to significant research efforts aimed at defining spatial configurations. While studies on office environments and work efficiency have actively utilized diverse designs across companies, research on the learning performance of educational spaces faces challenges. This causes an issue of limited renovations within educational facilities and restriction in exploring diverse spatial configurations. Overcoming these limitations, immersive virtual environments (IVEs) offer a solution by enabling experiences beyond physical constraints. This has applications across various domains such as cafes, gaming, exhibitions, and cultural activities. The construction industry has validated the effectiveness of IVEs on heritage restoration, safety simulation, and on-site experience [2]. Moreover, there is a growing body of research exploring the relationship between spatial configuration and work efficiency or learning performance through IVEs [3]. However, lack of research framework encompassing studies on spatial analysis, efficiency, and the use of IVEs has led to an uncertain trial-and-error in research efforts. This study proposes a framework for assessing the learning performance and creativity in spatial configuration by virtual reality (VR) and mixed reality (MR). By understanding the characteristics of VR and MR, cognitive tests can be designed to measure outcomes under identical conditions across virtual and real environments which offers a structured process for efficient experimental setup.

2. LITERATURE REVIEWS

2.1. Spatial configuration and learning performance, creativity in educational facilities

The spatial configuration of educational facilities significantly impacts the academic performance and creativity of students [4-5]. The analysis of indoor spatial elements affecting learning performance primarily utilizes the indoor environmental quality (IEQ). The relative standards exist in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [5-6]. IEQ comprises of ambient environment, elements that includes: air quality, thermal comfort, acoustic conditions, lighting, and outdoor air supply in open-plan offices, and spatial features such as spatial layouts, furniture, views, and configuration [5]. Spatial features are fundamental to IEQ elements that influence the performance and behavior of space users [7]. Unlike the ambient environment, which can be controlled through product selection or intensity adjustment, spatial features are determined through construction and require further construction for modifications that results in significant increase in cost and time. Therefore, it is necessary to conduct evaluations to verify their effectiveness prior to deciding on spatial features.

Spatial features such as furniture arrangement and layout have shown to correlate with students' learning performance [8]. However, given the nearly infinite options for furniture arrangements and layout configurations, scholars have conducted reviews to highlight their impacts. It has been established that the color of the room, material of floors and wall finishes, room types, views, and furniture all influence overall academic performance [3, 5, 9]. Nonetheless, the results vary depending on the type of study activity (individual study, group work, working alone in a group setting) presenting challenges in determining their effects.

The relationship between spatial configuration and creativity is a theme explored constantly within space design, with empirical studies confirming their connection. However, it still faces challenges in delineating a clear relationship or conducting in-depth analyses [1]. Factors such as spatial openness, furniture types and arrangements, greenery, indoor climate, and open spaces have been identified as significant [10-13]. With studies confirming that these aspects, including: spatial layout, color, finishes, and lighting has an impact on creativity. Moreover, the importance of environments in encouraging interactions among knowledge workers to stimulate creativity and innovation has been underscored [14]. Alongside the role of space and furniture configuration enhances creativity, productivity, and facilitates collaborative tasks through adaptable arrangements [15]. The indoor environment's quality has been linked to occupant productivity, with satisfaction levels that correlates to cognitive productivity and the physical working environment's satisfaction [6, 16]. This highlights spatial features such as layouts as critical [4, 6].

Table 1. Spatial features of educational facilities related with learning performance and creativity

Category	Contents	Factors	References
Configurations	Color of room	Learning performance	[3, 9]
		Creativity	[11]
	Material of floor finish	Learning performance	[3]
	Material of wall finish	Learning performance	[3]
Layouts	Open space	Learning performance,	[5]
		Creativity	[4, 6, 11, 12]
Furniture	Unusual furniture, activating furniture	Learning performance	[5]
		Creativity	[11, 15]
Types	Personal space, incubation space, collaboration space, experimentation space, analysis space, exhibition space, learning space, social space, relaxation space, illumination space, exploration space	Creativity	[17]
Views	Open views	Learning performance	[5]
		Creativity	[10]

To investigate the influence of variations in spatial features on learning performance and creativity, it is imperative to conduct a comprehensive analysis for the relevant content. Evaluating learning performance and creativity involves measuring key aspects such as working memory, attention, and cognition. Working memory, a critical component of human cognitive capacity, plays a significant role in learning efficiency [18]. Distinguished from short-term memory, working memory comprises of multicomponent system segmented into storage and executive attention control functions [19]. Techniques for assessing working memory include Span tests, Recall tests, and tests of spatial working memory which predominantly assess the ability to store and manipulate information during tasks; involving new knowledge acquisition, comprehension, and problem-solving [20]. These tasks necessitate sustained and focused attention for the selective retrieval of information pertinent to solutions [21]. Another crucial cognitive function is attention that can be quantified using tests such as: the Go/No-go test and D2-R that is based on times and accuracy that can be evaluated [3, 22]. The Stroop test is primarily utilized for measuring attention and cognition [3, 9, 32]. It is particularly effective in assessing momentary attention and cognitive abilities based on the interpretation of the meaning and color of displayed words. Creativity assessments offer insights into creativity across general domains through diverse methodologies, while also examining specific skills and abilities (e.g., mathematical skills including spatial abilities, algebraic reasoning, and number sense) to further validate the impacts on learning performance and creativity [23]. A detailed review of these elements is shown in Table 2.

Table 2. Test to identifying learning performance and creativity

Category	Test	References
Working memory	Span test	[3, 24-28]
	Recall test	[29]
	Spatial working memory	[3, 30]
	N-back test	[31]
Attention	Go/No-go test	[3]
	D2-R	[22]
Cognition	Stroop test	[3, 9, 32]
Creativity	Alternate Uses Test (AUT)	[33-34]
	Torrance Test of Creative Thinking (TTCT)	[32]
	Remote Associates Test (RAT)	[22, 28]

2.2. Immersive virtual environments

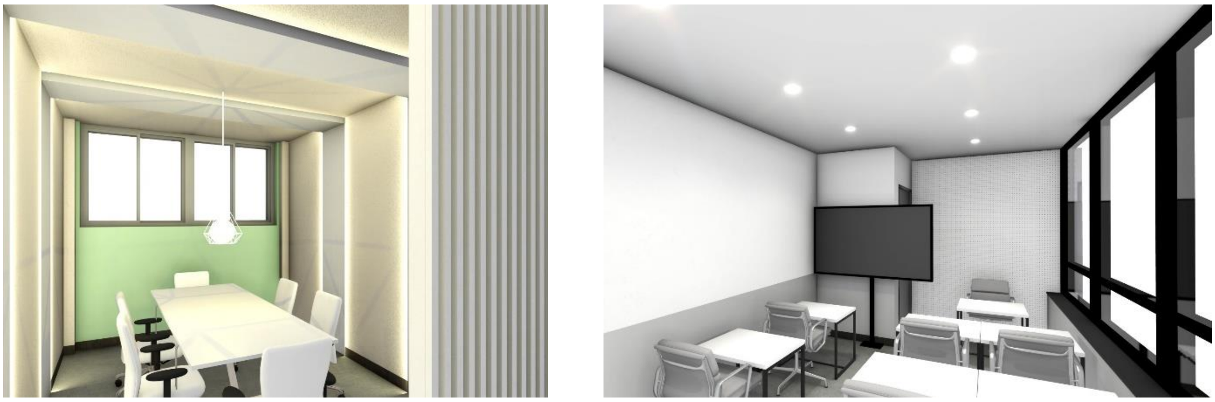
Studies on the urban environment evaluation comparing VR technology with real environments [35] and the research on subjective soundscape assessments in MR technology and real environments [36] demonstrate that the introduction and development of virtual environments can create immersive experiential spaces that mimic real spaces. In the architectural field, VR and MR are being used to provide diverse spatial experiences. VR technology, utilizing head-mounted display (HMD), completely isolated the user from the real-world and provides information and experience from the virtual environment only [37]. This offers the advantage of allowing users to experience a variety of scenarios without the constraints of physical surroundings. However, a limitation is that experiences are confined to the virtual information provided by the creators, as the real environment is entirely blocked out. MR technology, on the other hand, features an HMD with a transparent display, overlaying virtual environment information on the user's view of the real-world. This allows for interaction between the real and virtual environments, highlighting its distinct characteristics.

3. Framework

A framework for validating the learning performance in educational facilities utilizing virtual environments requires the following processes: 1) spatial features analysis. 2) virtual environments modeling, 3) tests design for analyzing learning performance in virtual environments, 4) experimental process

3.1. Spatial features analysis

The analysis of spatial features in planned educational facility spaces is crucial for identifying the elements within these spaces. Utilizing the spatial features index classified through prior theoretical review, it is necessary to determine which spatial elements related to learning performance and creativity are present in the space. The spatial features employed in educational facilities are organized into space configurations, layout, furniture, space types, and views. The analysis of a sample space is presented in Table 3.



(a) Space option 1 (b) Space option 2

Figure 1. An example of educational facilities spaces

Table 3. An example of educational facilities spatial features analysis

Category	Contents	Space option 1	Space option 2
Configurations	Color of room	Beige, green	White, grey
	Material of floor finish	Wood	Tile r
	Material of wall finish	Fabric	Wallpaper
Layouts	Open space	Face-to-face meeting	X
Furniture	Unusual furniture	X	X
	Activating furniture	X	X
Types		Collaboration space	Learning space
Views	Open views	X	X

3.2 Virtual environments modeling

To utilize virtual environments for simulating abstract spatial experience similar to the real-world, undertaking modeling work for the construction of VR and MR spaces identical to the planned space is essential. This process involves fixing the spatial plan using architectural blueprints (2D CAD plan) or 3D modeling utilized in actual space construction. These models are converted using Unity engine to establish the virtual environments. The process of virtual environments modeling is shown in Figure 2.

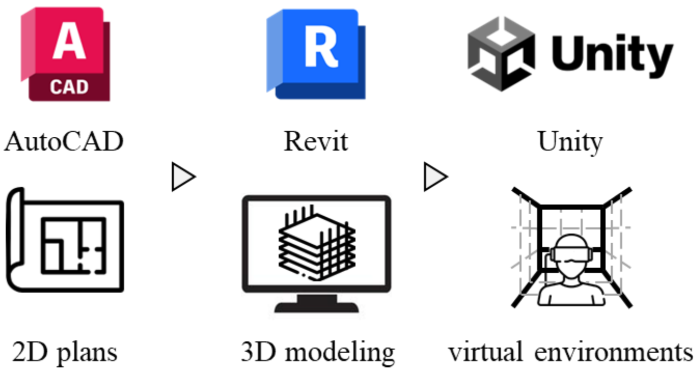


Figure 2. Virual environments modeling process

3.3 Tests design for analyzing learning performance in virtual environments

VR necessitates the complete occlusion of real-world stimuli and the engagement with virtual content through handheld controllers. This immersive environment introduces limitations to the range of tests that can be effectively administered within a VR setting. Notably, tasks that require interactions similar to those found in the real-world or MR environments, such as typing tests employing a keyboard (e.g. the Stroop test, Span test, and AUT), face challenges due to discrepancies in reaction times and the physical interaction models provided by VR. Given the inherent constraints of VR environments, a careful selection process is essential to identify assessments that accurately reflect cognitive and learning performances without being unduly influenced by the VR interface. Therefore, the N-back test, Spatial working memory updating, Go/No-go test, and TTCT-verbal test were chosen for measuring learning performance and creativity, respectively.

3.4. Experimental process

The following content is based on the constructed framework and discusses the efficient experimental process in IVEs and real spaces: (1) pre-assessment, (2) VR experiment, (3) MR experiment, (4) real-world experiments.

(1) **Pre-assessment**: To describe participants' perception status, Short Portable Mental Status Questionnaire (SPMSQ) was conducted initially [3]. Subsequently, the adaptation information to the virtual environment is assessed through simple operations within both the VR and MR environments.

(2) **VR experiment**: This stage involves conducting experiments within a VR environment providing comprehensive virtual environmental information to enhance the quality of experimental data. Tests, N-back test, go/no-go test, spatial working memory updating, and TTCT-verbal test, are administered randomly to each participant to maintain consistent experimental quality. After each experiment, a minimum of 3 minutes is allocated to ensure participants are not overstressed before proceeding to the next stage.

(3) **MR experiment**: Experiments using MR are conducted in the same space provided by the completed layout modelling. The experimental conditions and processes are identical to those in the VR experiment phase.

(4) **Real-world experiment**: Experiments are conducted within the real-world environment. This stage utilizes data to compare significant differences between the outcomes from the IVEs experiments and real environments.

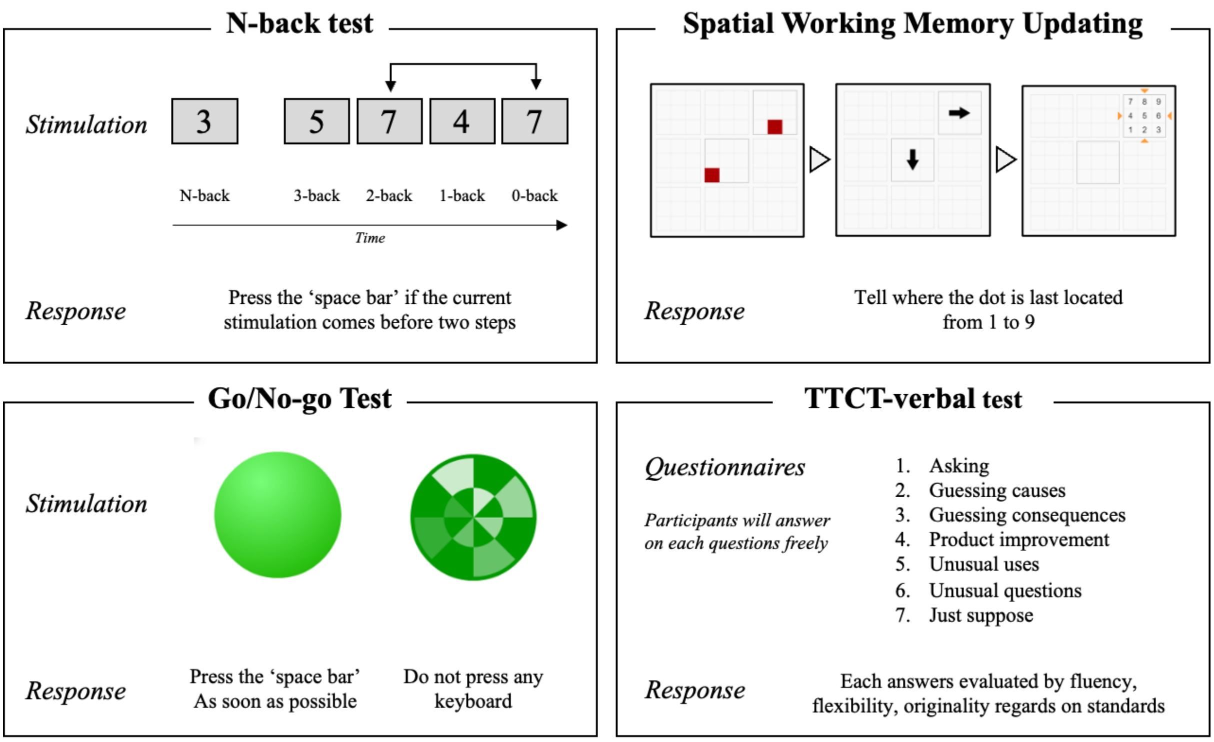


Figure 3. Cognitive tests for identifying the learning performance and creativity

4. CONCLUSION

This study proposes a framework for assessing the learning performance and creativity in educational spaces undergoing spatial configurations by IVEs. The methodology encompasses a series of steps. Firstly, analyzing the spatial elements of educational facilities to predict their impact on learning performance and creativity. The next step is to create analyzable environments by developing VR and MR modeling's. The analysis process is designed to eliminate potential response time gaps that may occur due to VR environmental factors, employing cognitive such as the N-back test, Go/No-go test, and Spatial working memory updating. In addition, the TTCT-verbal for assessing creativity. The final stage involves a comparative analysis of three environments' experimental data to identify differences.

By conducting a differential analysis of learning performance and creativity, the research aims to explore the feasibility of applying virtual environments on educational spaces. The insights gained from utilizing virtual environments in spatial planning are expected to be instrumental in aiding decisions before the construction.

REFERENCES

[1] K. Thoring, M. Gonçalves, R. Mueller, P. Desmet, & P. Badke-Schaub, "The architecture of creativity: Toward a causal theory of creative workspace design", International Journal of Design, vol. 15, no. 2, pp. 17-36, 2021.

[2] M. Han, B. Kwanyup, K. Lee, S. Ko, & J. Kim, "A Study on Supporting Design Decision Making in Office Building Remodeling Projects by Introducing Mixed Reality", Korean Journal of Construction Engineering and Management, vol. 22, no. 1, pp. 3-12, 2021.

[3] K. Lee, & J. Kim, "Relationship between psycho-physiological indicators and task performance under various indoor space designs for telecommuting environment by introducing mixed-reality", Scientific Reports, vol. 14, no. 1, 2024.

[4] N. Kwallek, C. Lewis, & A. Robbins, "Effects of office interior color on workers' mood and productivity", Perceptual and Motor Skills, vol. 66, no. 1, pp. 123-128, 1988.

[5] S. Hong, Y. Kim, & E. Yang, "Indoor environment and student productivity for individual and collaborative work in learning commons: a case study", Library Management, vol. 43, no. 1, pp. 15-34, 2022.

[6] S. Kang, D. Ou, & C. Mak, "The impact of indoor environmental quality on work productivity in university open-plan research offices", Building and Environment, vol. 124, pp. 78-89, 2017.

[7] Y. Al Horr, M. Arif, A. Kaushik, A. Mazroei, M. Katafygiotou, & E. Elsarrag, "Occupant productivity and office indoor environment quality: A review of the literature", Building and environment", vol. 105, pp. 369-389, 2016.

[8] F. Munir, A. Tharim, T. Mohd, & S. Said, "The Relationship Between Learning Space Attributes with Students' Satisfaction and Perceived Performance", Planning Malaysia, vol. 16, 2018.

[9] C. Liu, Y. Zhang, L. Sun, W. Gao, Q. Zang, & J. Li, "The effect of classroom wall color on learning performance: A virtual reality experiment", Building Simulation, vol. 15, no, 12, pp. 2019-2030. Beijing: Tsinghua University Press, 2022.

[10] J. McCoy, "Linking the physical work environment to creative context", The Journal of Creative Behavior, vol. 39, no. 3, pp. 167-189, 2005.

[11] Y. Martens, "Unlocking creativity with the physical workplace", Delft. University of Technology, The Netherlands, 2008.

[12] M. Meinel, L. Maier, T. Wagner, & K. Voigt, "Designing creativity-enhancing workspaces: A critical look at empirical evidence", Journal of technology and innovation management, vol. 1, no. 1, 2017.

[13] D. De Paoli, E. Sauer, & A. Ropo, "The spatial context of organizations: A critique of 'creative workspaces'", Journal of Management & Organization, vol. 25, no. 2, pp. 331-352, 2019.

[14] T. Allen, "Managing the flow of technology: technology transfer and the dissemination of technological information within the R&D organization", MIT Press Books, The MIT Press, Vol. 1, 1984.

[15] N. Sandström, R. Eriksson, K. Lonka, & S. Nenonen, "Usability and affordances for inquiry-based learning in a blended learning environment", Facilities, vol. 34, no. 7, pp. 433-449, 2016.

[16] D. Clements-Croome, "Creating the Productive Workplace", 2nd ed., Taylor and Francis, London, 2006.

[17] K. Thoring, R. Mueller, P. Desmet, & P. Badke-Schaub, "Spatial design factors associated with creative work: a systematic literature review", AI EDAM, vol. 34, no. 3, pp. 300-314, 2020.

[18] E. Tsigeman, S. Silas, K. Frieler, M. Likhanov, R. Gelding, Y. Kovas, & D. Müllensiefen, "The jack and jill adaptive working memory task: Construction, calibration and validation", PLoS One, vol. 17, no. 1, 2022.

[19] A. Baddeley, “The episodic buffer: a new component of working memory?”, Trends in cognitive sciences, vol. 4, no. 11, pp. 417-423, 2000.
[20] C. Lee, & D. Therriault, “The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes”, Intelligence, vol. 41, no. 5, pp. 306-320, 2013.
[21] B. Smeekens, & M. Kane, “Working memory capacity, mind wandering, and creative cognition: An individual-differences investigation into the benefits of controlled versus spontaneous thought”, Psychology of Aesthetics, Creativity, and the Arts, vol. 10, no. 4, 2016.
[22] K. Lunke, & B. Meier, “Disentangling the impact of artistic creativity on creative thinking, working memory, attention, and intelligence: Evidence for domain-specific relationships with a new self-report questionnaire”, Frontiers in psychology, vol. 7, 2016.
[23] M. Stolte, T. García, J. Van Luit, B. Oranje, & E. Kroesbergen, “The contribution of executive functions in predicting mathematical creativity in typical elementary school classes: A twofold role for updating”, Journal of Intelligence, vol. 8, no. 2, 2020.
[24] N, Jordan, J. Glutting, & C. Ramineni, "The importance of number sense to mathematics achievement in first and third grades", Learning and individual differences, vol. 20, no. 2, pp. 82-88, 2010.
[25] W. Lin, & Y. Lien, "The different role of working memory in open-ended versus closed-ended creative problem solving: A dual-process theory account", Creativity Research Journal, vol. 25, no. 1, pp. 85-96, 2013.
[26] P. Furley, & D. Memmert, "Creativity and working memory capacity in sports: working memory capacity is not a limiting factor in creative decision making amongst skilled performers", Frontiers in Psychology, vol. 6, 2015.
[27] B. Smeekens, & M. Kane, “Working memory capacity, mind wandering, and creative cognition: An individual-differences investigation into the benefits of controlled versus spontaneous thought”, Psychology of Aesthetics, Creativity, and the Arts, vol. 10, no. 4, 2016.
[28] C. Lee, & D. Therriault, "The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes." Intelligence, vol. 41, no. 5, pp. 306-320, 2013.
[29] R. Lu, Y. Zhang, N. Bao, M. Su, X Zhang, & J Shi, "Visuospatial, rather than verbal working memory capacity plays a key role in verbal and figural creativity", Thinking & Reasoning, vol. 28, no. 1, pp. 29-60, 2022.
[30] E. Kroesbergen, & E. Schoevers. "Creativity as predictor of mathematical abilities in fourth graders in addition to number sense and working memory", Journal of Numerical Cognition, vol. 3, no. 2, pp. 417-440, 2017.
[31] E. Aronen, V Vuontela, M. Steenari, & J. Salmi, "Working memory, psychiatric symptoms, and academic performance at school", Neurobiology of learning and memory, vol. 83, no. 1, pp. 33-42, 2005.
[32] S. Sharma, & N. Babu. "Interplay between creativity, executive function and working memory in middle-aged and older adults", Creativity Research Journal, vol. 29, no. 1 pp. 71-77, 2017.
[33] R. Richards, "A comparison of selected Guilford and Wallach-Kogan creative thinking tests in conjunction with measures of intelligence", Journal of Creative Behavior, vol. 10, no. 3, pp. 151-164, 1976.
[34] L. Wang, J. Plucker, Q. Wang, X. Xu, & W. Pang, "High schizotypal individuals are more creative? The mediation roles of overinclusive thinking and cognitive inhibition", Frontiers in psychology, vol. 9, 2018.
[35] V. Puyana-Romero, L. Lopez-Segura, L. Maffei, R. Hernández-Molina, & M. Masullo, “Interactive soundscapes: 360-video based immersive virtual reality in a tool for the participatory acoustic environment evaluation of urban areas”, Acta acustica united with acustica, vol. 103, no. 4, pp. 574-588, 2017.
[36] J. Hong, B. Lam, Z. Ong, K. Ooi, W. Gan, J. Kang, & S. Tan, “A mixed-reality approach to soundscape assessment of outdoor urban environments augmented with natural sounds”, Building and Environment, vol. 194, 2021.

[37] J. Im, S. Hwang, J. Jang, J. Kim, & K. Lee, "Introduction of Mixed Reality on Special Tree Landscape Design Review Phase", Journal of the Architectural Institute of Korea, vol. 38, no. 8, pp. 71-81, 2022.