Enhancing Collaborative Learning in Architectural Design Education Through Human-Computer Interaction and Game-based Learning

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This study uses a game-based learning approach to develop a collaborative environment for basic design in architectural education and examines its impacts. The foundational concept of the virtual environment is the playground, defined by Walz (2010) as a bounded space where play occurs. The virtual playground is introduced to basic design students based on the CIX game (1996), developed from a geometry-based system by architect Fabien Vienne (1925-2016). CIX is reconstructed in a multi-user virtual playground with Simlab Soft simulation software, facilitating interactive and collaborative design environments. The VR-enhanced environment is adapted to facilitate the playground for a basic architectural design platform. To assess the effectiveness of the participatory design experience proposed with the multi-user environment, the Collaborative Learning Assessment (CLA) (Muñoz-Carril et al., 2021) and Game Experience Survey (Martin-Dorta et al., 2014) are conducted. The findings suggest that a game-based collaborative design environment offers significant potential for immersive, interactive, and impactful learning experiences and can be an effective tool for basic design studios.

Keywords: *Architectural Design Education, Collaborative Learning, Virtual Environment, Game-based Learning, Human-Computer Interaction (HCI)*

INTRODUCTION

As the digital environment continues to evolve, new virtual tools and platforms that can be used in architectural education continue to emerge. Integrating collaborative virtual environments into architectural education allows students to engage in innovative design processes that foster creativity, spatial understanding, and teamwork (Bashandy, 2020; Yu et al., 2022; Darwish et al., 2023; Stephan et al., 2023;). Despite the rapid expansion of immersive virtual environments, the studies regarding collaboration design in virtual environments, especially in the early design phases, are still limited (Yu et al., 2022). In this context, immersive virtual environments with game-based approaches can expand architectural design education studies, primarily through basic design studios. In this regard, the study aims to address the following questions:

- How does the use of a virtual environment affect collaborative learning in architectural education?

- How does the prior VR Tool Experience affect the perceived usefulness of the virtual environment?
- How does game-based learning impact the design experience?

The foundational concept of this study is a virtual environment offering game-based learning in the form of a playground. Playground is defined by Walz (2010) as a bounded space where play occurs in ludic space. In this regard, this study explores the impacts of using a virtual playground to enhance collaborative learning in architectural design education. The introduced environment is called as Virtual Playground for Architectural Design (VPAD). The primary objective of VPAD is to facilitate the development of dynamic spatial compositions and expressive architectural forms by students in the first-year architectural design studios, where students are introduced to the fundamental principles of spatial form-making and see how collaborative engagement in the virtual environment aids in students' learning.

BACKGROUND

Game-based learning

Avedon and Sutton-Smith (1971) define a game as a repeatable pattern, a conflict between forces with an outcome, all bounded by the rules. However, Crawford (1984) states the distinguishing factor that separates a game from a non-game activity is the presence of an interactive element. The game is an interconnected system in which players interact with each other and with content (Kapp, 2012) and requires active participation from the audience, like a stage where the players create their performances reflecting active engagement (Costikyan, 1994).

Game-based learning (GBL) is a form of gameplay with clear learning outcomes (Plass et al., 2015), and may involve the use of educational game software for learning (Al Fatta et al., 2018). The GBL approach is employed for communication and strategy development in complex, challenging, and technical subjects (Prensky, 2003). The design of GBL requires the right balance between the representation of the subject and the prioritization of gameplay (Plass et al., 2015).

GBL's scope encompasses numerous disciplines and game genres as framed by Tang et al. (2009) (Figure 1). The domain is referred to as edutainment (a combination of "education" and "entertainment") (De Lope and Medina-Medina, 2017) and comprises educational games, educational simulators, and serious games.

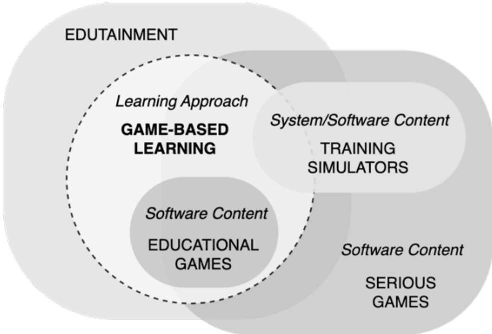


Figure 1
The game-based learning frame is adapted from Tang et al. (2009).

Educational games are the ones designed to achieve certain learning outcomes while playing. Serious games are "mental contest"s in the form of entertainment within a computer setting, played with a set rules to achieve goals in different objectives (Zyda, 2005). Simulator applications are the ones where participants are assigned roles in novel and unique realities to simulate challenging and costly situations that cannot be experienced in real life (Gredler, 1996).

However, with its references to entertainment and problems related to the level of engagement in gameplay (Charsky, 2010), edutainment applications are often seen as a lesser effective form of education.

Design games

Within the broad framework of GBL, design games are the ones that integrate design tools and digital games. They often facilitate exploration, and do not necessarily require to complete a whole game with strict rules and finish up in win-or-lose situations (Westre, 2013). Design games offer a playful method to engage co-design partners (Vaajakallio and Mattelmäki, 2014).

The integration of gameplay into architectural design contexts can be traced back to the 1970s. The precedent studies (Feldt, 1972; Green, 1979; Bonta, 1979) developed for architectural design studios had diverse objectives such as urban planning, construction, and decision-making. They were designed for different forms of play, including physical structures like cards, boards, and building blocks. The building blocks used to explore the geometric possibilities of the design problem in various scales were a prominent part of the game studies in the architectural design process (Green, 1979; Bonta, 1979; Doma and Şener, 2022; Song and Zhao, 2023).

Collaborative virtual playgrounds for architectural education

Huizinga (1980) states that the most critical feature of the play is its segregation from real life by its spatiality. Play involves stepping out of "real" life and entering a unique “temporary sphere of activity.” Playgrounds are temporary worlds within the ordinary world, dedicated to a specific activity separate from ordinary life. By the same token, a playground in a design game may be considered as a temporary and/or supplementary world in the design studio.

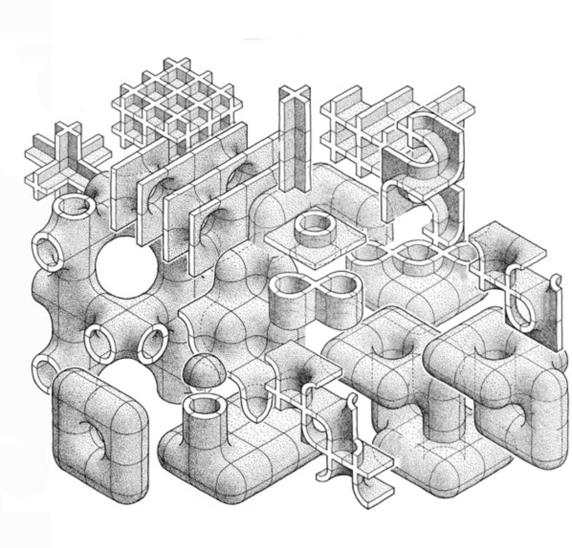
Previous studies indicate that the immersive and interactive interfaces of the game systems have the potential to alter educational practices (Kapp, 2012) and affect design processes (Kalay and Jeong, 2003). Furthermore, with the extended reality (XR) technologies, immersive environments can be integrated within the studio environments, thereby gradually transforming the tactile experiences associated with such environments (Donath and Regenbrecht, 1996).

“Realtime Architecture Platform” is such a playground that enables pervasive collaboration in real-time on the same architectural prototype with repetitive elements and assembly operations (Grasser et al., 2020) utilizing augmented reality (AR) technology for user-created content. Another virtual platform for design experiments is VoxelCO (Grasser, 2019). This multiplay environment facilitates real-time collaborative interaction and offers a virtual playground as a simple game, allowing users to place and remove virtual voxels. One of the most influential of such environments is Minecraft, a game initiated as a mapping tool in 2011 to socially engage users in different fields, from education to city planning (Bashandy, 2020). Among the various modes of Minecraft, the creative mode is preferred in participatory efforts as it allows the players to move and build freely.

METHODOLOGY

Concept: CIX, a topological toy

Fabien Vienne is a French architect who has worked on numerous architectural designs and experiments, from urban design to toy design. Vienne's CIX game blocks are one of his geometric structure studies that introduces many possibilities in a box-based grid system. In the CIX catalog (1996), Vienne stated that the CIX game blocks can be used in different fields, including education, and are suitable for digital reproduction.



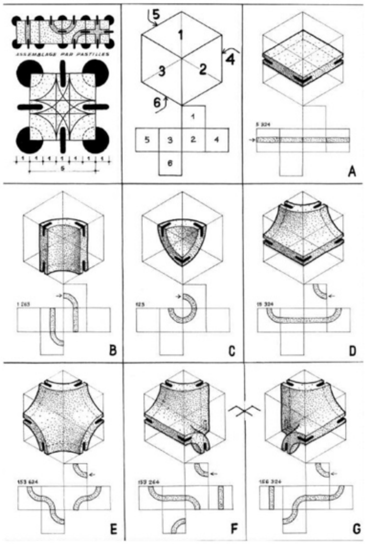


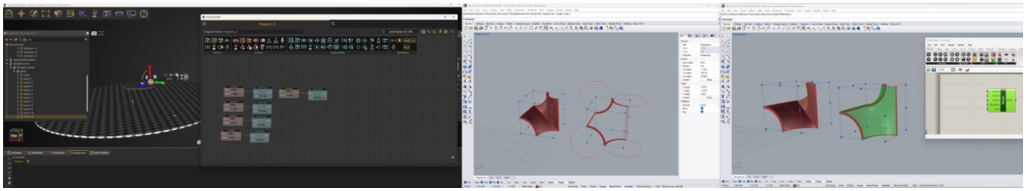
Figure 2
The virtual cubic space and the placement of CIX Building Blok Set (Vienne, 1996).

CIX game blocks are topological construction toys that materialize the spatial curvature concept. In the CIX game, players construct a variety of surfaces, including flat and curved ones, by utilizing a set of interlocking pieces. The pieces, each exhibiting a distinctive curvature and defined thickness, can be arranged within a virtual cubic space, as shown in Figure 2. The virtual cubic space is an abstract representation defined by a series of cubes of identical dimensions arranged in alignment.

Development of the collaborative virtual design playground

The design of VPAD is based on the concept of a "temporary sphere of activity," as described by Huizinga (1980). This concept is utilized to define the boundaries of play, which informs the overall design of the virtual playground. VPAD represents a collaborative learning experience that takes place in a virtual playground with Vienne's CIX game blocks. VPAD comprises 11 CIX elements created digitally in Rhinoceros Grasshopper software (Figure 3).

The virtual playground employs the grid-based design strategy (Stephan et al., 2023) to guide the participants to move and gather the CIX elements. The grid-based virtual playgrounds of the environment facilitate the possibility of more precisely gathering the virtual cubic edges of the CIX elements. The temporary sphere of VPAD is



structured with two virtual playgrounds on top of each other to facilitate different scales (Figure 4).

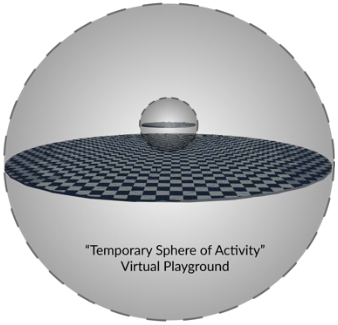


Figure 4
Virtual playground of VPAD

Similar to the design games inside the GBL framework, the structure of VPAD adopts an open-ended and exploratory approach to design education. The formal rules of a game do not define VPAD; therefore, it offers participants a rule-based structure that follows grid and surface interconnections, guiding the play and learning experience. This structure balances the challenge of working collaboratively with the players' skills while maintaining engagement and interest.

The virtual playground is generated in the Simlab Soft VR Studio (2023) and experienced in VR Viewer inside Meta Oculus Quest headsets. The virtual CIX catalog interface provides access to various design elements. The user can manipulate CIX objects using VR controllers, scaling them to varying sizes and rotating them along the X-Y axes. The application offers a scale-copy-delete function, which facilitates rapid modifications and the creation of duplicates.

Implementation in the design studio

The collaborative impact of VPAD is tested with two-participant groups in VR-enhanced sessions. The sessions adopted a structured approach, beginning with demographic questions and continuing with students' immersion in the virtual playground. Each session lasted 30 minutes long.

The sessions are held at Bilkent University and Ostim Technical University. The participants are students in the first-year undergraduate programs in both universities. Bilkent University sessions involved 14 first year design students, while Ostim Technical University session involved 24 students. Participating students from both universities voluntarily took part in the sessions.

Data Collection and Analysis

Data collection methods of the study include final design models, VR session videos, photos from the sessions, answers to the demographic questions, and to the surveys. After the sessions, Collaborative Learning Assessment (CLA) devised by Muñoz-Carril et al. (2021) is employed to assess the experimental process. Also Game Experience Survey by Martin-Dorta et al. (2014) is conducted after the sessions are completed.

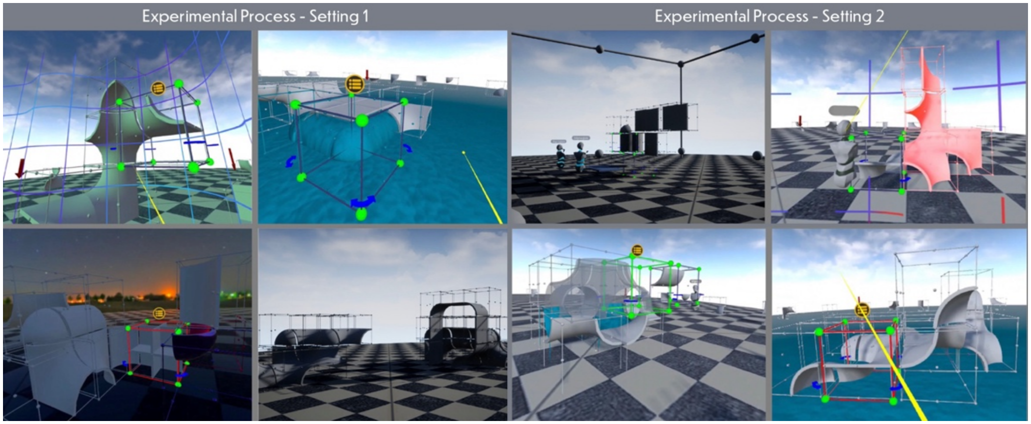
CLA is a model adapted from Technology Acceptance Model (TAM), Expectancy-Confirmation Theory (ECM), and Flow Theory (Csikszentmihalyi, 2014). TAM, proposed by Fred Davis (1986), is an extensive tool for understanding user acceptance and usage behavior in various fields (Davis, 1986). ECM, initially proposed by Oliver (1980), measures the impact of consumer expectations and their post-purchase perceptions on overall consumer satisfaction with a product or service in the marketing field. Flow Theory is characterized by narrowed consciousness and focused attention on the present moment and the surrounding environment. In the flow state, the individual is not subject to the need for conscious reflection, and as a result, feedback is clear and immediate, providing

Figure 3
The creation process of the environment and elements of VPAD in the Simlab Soft VR Studio (2023) and Rhinoceros Grasshopper software

automatic responses (Csikszentmihalyi, 2014). In an ideal flow experience, involvement can be achieved without considering the results.

The data analysis involves an evaluation of the associations between the CLA statements and the descriptive analysis of the Game Experience Survey held after the sessions. The data analyses are conducted using the statistical software program SPSS. The non-parametric analysis employs Fisher's Exact Test to assess the correlations between demographic questions and statements of the survey about collaborative learning.

RESULTS
Final designs
The final designs produced during the VPAD sessions demonstrate notable variations, reflecting the diverse strategies employed by the two different participant teams. Different sessions involve alterations to the materials used for the elements or the playground itself. Another strategy employed by the different session teams was the manipulation of scale. This involved playing with proportions of CIX elements to create unique spatial experiences (Figure 5).



Descriptive Analysis of the Collaborative Learning Assessment							
	Perceived Ease of Use	Perceived Usefulness	Attitude	Confirmation	Perceived Enjoyment	Satisfaction	Perceived Impact on Learning
N	38	38	38	38	38	38	38
Mean	4,29	4,06	4,47	4,36	4,71	4,43	4,27
Median	4,25	4,53	4,75	4,67	5,00	4,50	4,50
Mode	4,25	4,60	5,00	4,67	5,00	4,50	4,75
Std. Deviation	0,396	0,495	0,586	0,65	0,381	0,467	0,659

Collaborative Learning Assessment results

In the Collaborative Learning Assessment (CLA) carried out after the collaborative VPAD sessions, Cronbach's alpha coefficients are estimated for each item and are higher than 0.8. The CLA constructs are descriptively analyzed (Table 1).

The correlations between the VR tool familiarity question in the demographic survey and the CLA statements are assessed using Fisher’s Exact Test (Sauro and Lewis, 2012). It was found that there is a statistically significant association between prior VR tool experience and Perceived Ease of Use, Fisher's Exact Test (1, N=38) = 12.638, p=0.026; less than the threshold value of significant level 0.05 (Table 2).

VR Tool Experience is significantly associated with Perceived Usefulness, Fisher's Exact Test (1, N=38) = 12.638, p = 0.048 (Table 2). Those without experience with VR tools find the collaborative learning process and application more useful, with a notable concentration at higher scores (4.60). This indicates that familiarity and repeated use of VR tools might moderate the perceived usefulness.

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Table 2
Associations between VR tool experience and CLA constructs using Fisher’s Exact Test

	Value	Exact Sig. (2-sided)
VR Tool Experience - Perceived Ease of Use		
Fisher's Exact Test	12,638	0,026*
VR Tool Experience - Perceived Usefulness		
Fisher's Exact Test	13,697	0,048*
VR Tool Experience - Perceived Enjoyment		
Fisher's Exact Test	12,968	0,003**
N of Valid Cases	38	

Note. **Correlation is significant at the 0.01 level (2-tailed).

		Very Unlikely		Unlikely		Neutral		Likely		Very Likely	
		%	N	%	N	%	N	%	N	%	N
1	MPAD was easy to understand.	0,00%	0	2,60%	1	10,50%	4	36,80%	14	50,00%	19
2	I felt capable of solving tasks.	0,00%	0	2,60%	1	15,80%	6	28,90%	11	52,60%	20
3	The game stimulates my interest.	0,00%	0	0,00%	0	0,00%	0	21,10%	8	78,90%	30
4	I think it's a nice tool for development of the spatial ability.	0,00%	0	0,00%	0	7,90%	3	23,70%	9	68,40%	26
5	I would recommend this application to my classmates.	0,00%	0	0,00%	0	0,00%	0	21,10%	8	78,90%	30
6	I think that metaverse and game-based learning is a good learning system.	0,00%	0	0,00%	0	2,60%	1	23,70%	9	73,70%	28
7	I would have rather performed this course with the teacher physically present.	31,60%	12	31,60%	12	15,80%	6	13,20%	5	7,90%	3

Table 1
Descriptive Analysis of The Collaborative Learning Assessment (CLA) (Muñoz-Carril et al., 2021)

Game Experience Survey results

The participants were asked to complete a game experience survey about their gaming experience at the end of the sessions. Each statement in the questionnaire reflects a different aspect of the VPAD experience. The survey is descriptively analyzed, as shown in Table 3. The survey results show a positive reception of the VPAD, with higher ease of understanding, perception of developing spatial skills, and overall agreement on the benefits of the game-based learning system. In addition,

Table 3
Descriptive Analysis of Game Experience Survey (Martin-Dorta et al., 2014)

despite the positive results of the digital game-based process, a significant proportion of respondents indicated a preference for the tutor's physical presence.

DISCUSSION

The findings of this study reveal that the collaborative VR-enhanced environment positively affects the design experience in architectural education by providing an interactive space. The immersive environment of VPAD enhances real-time collaboration and creative exploration. Additionally, integrating the game-based learning method into the collaborative sessions positively influences the virtual design experience.

The virtual playground served as an ideal canvas for experimentation, allowing students to push the boundaries of the CIX elements' connection to generate unique collaborative results. The diverse approaches adopted by the participants resulted in creating innovative textures and practicing manipulating the scale and proportions.

The results of the VPAD experimental study highlight the potential of using game-based and collaborative approaches in first-year design education for architecture. Implementing a collaborative virtual environment is an effective design medium, with CIX elements facilitating an exploration design tool alternative within virtual reality.

LIMITATIONS AND FUTURE DIRECTION

It is observed that there can be several improvements to the virtual playground application in further studies and experiments. Further developments in the application can allow users to fly and climb objects in a virtual reality environment, which would improve the user experience in movement. The participants in this study proposed the inclusion of a snapping feature to facilitate the assembly process. The ability to select and copy multiple elements simultaneously within a multiple transformation was suggested as a helpful feature.

Moreover, the experimental process can be enhanced by larger groups. Having teams of 4-5 members may facilitate a more enjoyable design process and may result in generating a broader range of design options. The participants also suggested that multiple sessions can enhance familiarization with the tool. The latter phases can focus on the design process solely to emphasize the adaptation needs. Additionally, virtual learning environments like VPAD can be balanced with traditional face-to-face instructions in the further phases.

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