Augmented reality experience in an architectural design studio

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Abstract

Thanks to the developing technology, different methods and tools are used in architectural representation, and architects contribute to developing these tools. Architects can easily model their designs with computer technologies and even make them visible in the environment with augmented reality technologies. Also, it is thought that these technologies will become widespread in basic architectural education over time. This study conducted a practice at the undergraduate architecture level using augmented reality technology. Within the scope of the study, the predisposition of students who experience augmented reality technologies to new representation, gender, course period, familiarity with playing computer games, the effect of computer programs that they can use in their previous augmented reality experience and designs if any, and the correlation between them has been tried to be revealed with this study. In this context, a study was carried out with thirteen students in the architectural design studio. Students were expected to parametrically design indoor exhibition elements using Rhinoceros 3D software and the Grasshopper plugin in the study. Then, an experimental augmented reality study was conducted with the Fologram, in which the students transferred these virtual exhibition elements they designed to the real indoors and reshaped them according to the space. Afterwards, a questionnaire consisting of five independent and ten dependent variables was applied to the students. The survey results were analysed with the IBM SPSS Statistics program. According to the results obtained, significant results were determined between 4 independent variables and one dependent variable.

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1 Introduction

In architecture and interior design education, the design studio is the principal place where design skills are gained, and multiple productions and discussions are carried out. This educational process consists of research, interpretation, and discussion methods to contribute to the basic knowledge of past productions and the creation and fiction of the future. One of the most critical challenges for the designer in the interior design process is the problem of working on a scaled-down representation of something that is elsewhere and often of larger size. The nature of space design requires the designer to sharpen their ability to think other-centred within a representation that resembles the place on another scale but cannot be there [34].

The physical and digital models, which are the representation tools of architectural and interior design, cause the creation of out-of-context formations that include human–environment-oriented data and relationships. In Lefebvre's words, this visuality, which reduces objects to a reflective and surprising abstraction, overlaps with scientific conception and analytical methods [26] and causes formations unrelated to the contextual elements of people and places are based only on scientific thought and technological developments.

When we look at scale definitions in architecture, it is striking that the quantitative aspect of scale is generally mentioned [3, 7, 9, 18, 31].

Lahoud [24] states that the concept of scale is not only a qualification, it also exists in determining the vital relationship of something with another and the combination of the elements, and it should be evaluated within this framework. This context reveals that the concept of scale is not only quantitative but also exists with its qualitative expansions in the determination of the vital relationship of one thing with another and the combination of the elements and should be evaluated within this framework [21]. This situation is challenging in architectural education. In the architectural design studio, 1/1 scale models cannot be realised due to ethical, financial reasons, the solid and indestructible material, lack of workforce and real environment, and architectural representation is realised by making a physical model and/or digital model on a smaller scale.

However, Augmented Reality (AR) technologies are thought to eliminate all these difficulties. With AR, the user can access information about the object of interest while experiencing the real world at the same time. In this context, an AR technology study was conducted in the architectural design studio on architectural education through a three-week augmented reality experience. Within the scope of the study, the predisposition of students who experience AR technologies to new representation, gender, course level, familiarity with playing computer games, the effect of computer programs that they can use in their previous augmented reality experience and designs if any, and the correlation between them has been tried to be revealed with this study.

2 Architecture and augmented reality

In parallel with the development of computer-aided design (CAD) software, digital representation tools have been developing and changing rapidly since the 1950s. This adventure, which started with the SAGE (Semi-Automatic Ground Environment) air defence project developed in MIT's Lincoln Laboratory for the American Air Force in the mid-1950s, has continued with various CAD programs, solid modelling, NURB-based parametric design interfaces, and animation programs. These developments are accompanied by

virtual reality (VR), augmented reality, and mixed reality technologies that enable them to be viewed [1, 2]. Charles M. Eastman [12] described the pioneering developments in CAD technologies from Sketchpad to virtual reality with the following timeline (Fig. 1).

Many reviews have been published in the style of historical chronology, emphasising the evolution of augmented reality research [4, 6, 28]. Based on these studies, the hardware, software, technical and theoretical developments that constitute the building blocks of augmented reality are shown in the timeline in Fig. 2.

After commercialising augmented reality technology, it has become an interactive tool that can be used more efficiently in many technical fields, including architects. Interaction in augmented reality occurs directly, indirectly, mirrored, and embedded. Using indirect head-worn displays (HMDs), it is possible to describe scenarios where the user interacts directly with the computer system [25, 30]. In indirect interaction, this configuration, typical in many existing mobile augmented reality applications, allows users to interact with the virtual via a mobile device (usually a smartphone or tablet) equipped with a tactile screen. In mirrored interaction, a stationary computer is placed in front of the platform that displays an augmented and reflected view of the user's real environment. In embedded interaction, scenarios integrating virtual elements into the real environment are created using several screens, projectors, or holographic images (Fig. 3) [29].

Chen (2013) has gathered augmented reality features under twelve headings. These can be listed as follows, combining virtual and real objects in the natural environment, real-time interaction environment, creating an immersive environment, multimedia, and multi-sensor display, portability, user-friendliness, attention-grabbing, interactivity, providing a sense of existence, conceptual learning, real observation and perception, sense engine, and return. These advantages mentioned by Chen enable augmented reality technologies in many fields such as gaming, archaeology, art, trade, education, medical, military, and architecture.

Due to the close relationship between architecture and 3D representations, it is seen that many augmented reality experiences have been studied in the architectural discipline recently. Augmented reality systems are used not only in architectural and interior design but also in visualisation as a new form of presentation to obtain information in project implementation and management. In the light of the studies done so far, the use of augmented reality in the field of architecture can be mentioned under five main headings. These are architectural visualisation and presentation, architectural design, preservation, and restoration, building implementation and management, location-based information, and architectural education [27].
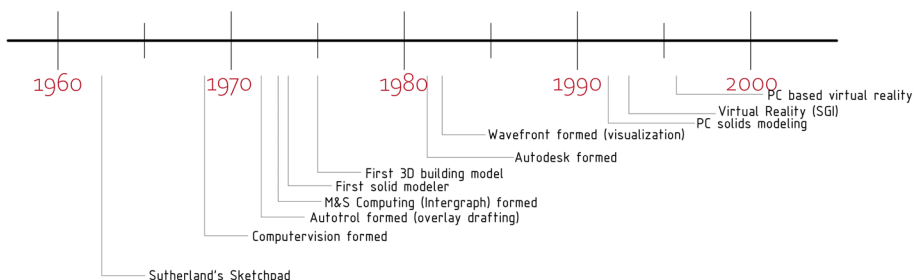

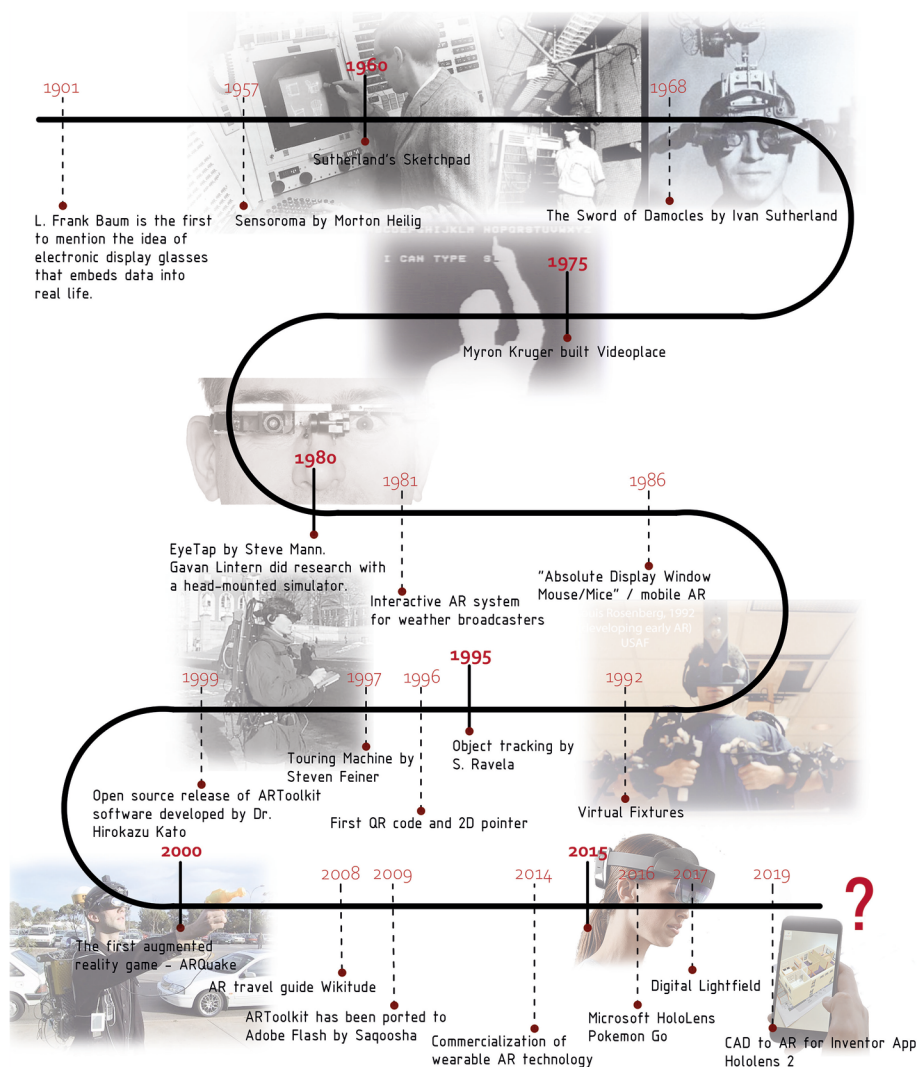**Fig. 1** Charles M Eastman 1999 CAD timeline

Fig. 2 Time travel of augmented reality (Compiled by the Authors)

2.1 Augmented reality in architectural education

When the use of augmented reality technology within the scope of architectural education is examined, it is seen that many applications have been developed, especially in the last ten years, and the studies have gained momentum in the previous few years [10]. With the emergence of augmented reality, it is possible to match architectural education's physical and virtual demands. Ensuring this match with augmented reality may offer the opportunity to make radical reforms in the architectural education system. When the research in
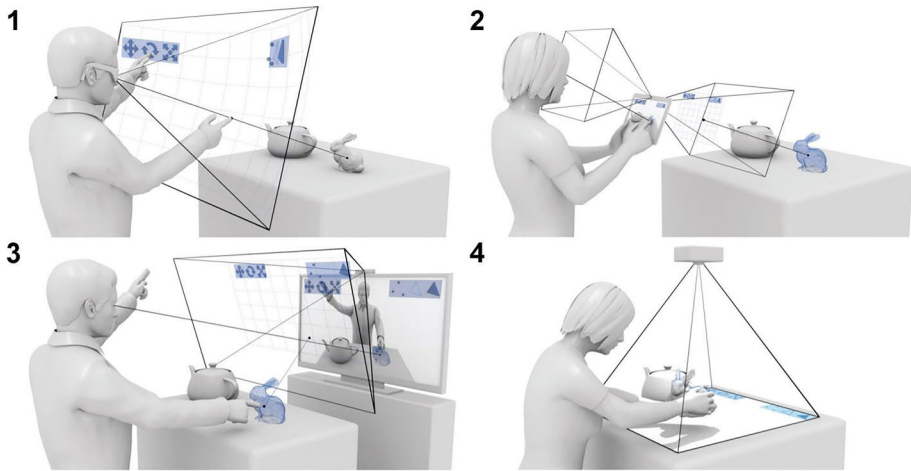
Fig. 3 Interaction in augmented reality is (1) direct, (2) indirect, (3) mirrored, and (4) embedded [29]

this field is examined, it is seen that there are a limited number of studies, especially on undergraduate education in architecture.

As seen in Fig. 4. Research using AR in architectural education was evaluated with the following criteria: significant developments in augmented reality effects, AR tools used, how AR was used in architectural education and the developed applications during the study. After this evaluation, studies were classified and explained under the following headings.

2.1.1 Studies on the collaborative method of AR applications

Gül [19], in a collaborative study, revealed the design differences between mobile augmented reality and the real environment by protocol analysis. An application for city design education was created by combining touchable interfaces and augmented reality systems by Chen and Wang. They created an application for city design education by combining touchable interfaces and augmented reality systems [8]. The results obtained from the experiments indicate that augmented reality can concretely improve design activities in some collaborative studies. Abdullah et al. [3], creating a collaborative working environment,
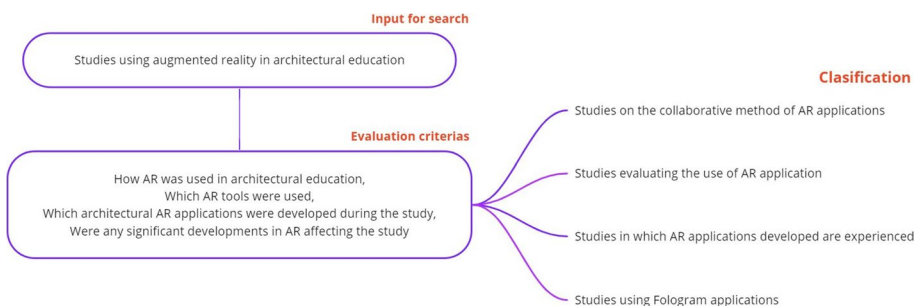

Fig. 4 Evaluation and classification of studies using AR in architectural education

carried out a study in which architecture students presented the carrier steel details they developed together in the form of augmented reality models. Grasser [18] explored the potential of collaboratively playing with augmented and mixed realities objects. VoxelCO, a multiplayer gaming platform developed by the author, creates a speculative playground for research, interacting with things and people and providing new opportunities to interact deeply with its content and context.

2.1.2 Studies evaluating the use of AR application

Fonseca et al. [14] questioned the use of augmented reality in architectural education in their study. According to the findings, it was stated that augmented reality systems are acceptable instead of traditional photomontage methods. In his research, Chandrasekera [7] experienced alternative modelling strategies that use technologies such as VR and augmented reality in architecture and interior architecture education through the Technology Acceptance Model to understand better how students perceive design solutions in early design studios. As a result of the study, the students compared the physical models with the augmented reality models and stated that the augmented reality technology is easier to use. In the study of [31], 11 participant students were asked to make a design proposal for a campus with the help of mobile devices that can use augmented reality technology. The proposed design is aligned to actual terrain with the help of GPS systems. Evaluation of the study was made with the help of a questionnaire applied to the students. Fonseca et al. [16] analyse the impact of new interactive and gamified visualisation systems on urban design projects and inclusion in architectural education as an educational tool.

It is reported that students are initially not motivated using digital systems, but after the students complete the fieldwork, their motivation increases significantly.

2.1.3 Studies in which AR applications developed are experienced

Riera et al. [31] carried out a study with the U-AR application, designed to be used in the architectural education environment, recognising the images in the real environment as markers and placing 3D virtual models in this real environment. With the application, experiments were carried out by forming three separate groups in which 20 students participated.

The students in the first group worked with the U-AR application. The students in the second group worked with a similar augmented reality application available in the market. The students in the third group worked with the traditional slide-based method. At the end of the study, it was concluded that AR-based systems motivate students more. Köymen and Tong [23] developed an application called SketchAR, an augmented reality-supported software experiment that models sketch in real-time 3D in the architectural pre-design process. With the developed software named SketchAR, the sketch work made by the user on any paper is transformed into 3D wall objects in real-time in the augmented reality environment. After the software was completed, a questionnaire was applied to the students. According to the survey results, it has been revealed that SketchAR can be an effective software that can be used in the field of architectural design with a success rate of over 90%. Vassigh et al. [35], with the AR-SKOPE mobile application, was aimed for students to learn about the architectural structure in the real environment. In the study carried out with the building information model and augmented reality integration, the location was determined by GPS. Many detailed

drawings of the building, such as architecture and structure, were displayed in the real environment. Fonseca et al. [15] aimed to evaluate the spatial perception of historical buildings, which are world heritage, in an educational framework by using wearable technologies. The study used a video-guided and indoor location-based system and evaluated the students who visited the Casa Batllo Museum. A problem was detected in the synchronisation between the student location and the multimedia content in the process. However, compared to the classical audio guide, students stated that they had a better understanding of the museum's features thanks to the multimedia content. Kerr and Lawson [22] outlined the development of Master of Time, an augmented reality prototype created to educate first-year design students and non-designers in the fundamental principles of landscape architecture. This study examines augmented reality technology's learning potential and benefits, focusing on creating new applications in digital storytelling through experiences. The authors propose a set of critical design principles, strategies, and methodologies that educators can apply when developing interdisciplinary augmented reality learning experiences. As a result of the study, they concluded that the Master of Time project was successful at more than one level as a landscape design education tool.

In studies where augmented reality systems are used in education, it is seen that devices such as smartphones, tablets, and laptop computers are frequently used. Thanks to these devices, an augmented reality experience is possible with low costs regardless of time–space. In particular, the student's experience with their smartphone allows a student-centred study at their own pace. One of the online studies using augmented reality on this topic was conducted by Goepel and Crolla [17] at the 2021 Digital futures world conference. Participants were asked to use their smartphone as an augmented reality device to mould a digitally given object out of clay. However, as a result, it turned out that it is tough to build something with a smartphone in practice.

It is known that the most popular applications of Augmented Reality in architecture are Augin and Trimble for Revit, SketchUp Viewer for SketchUp, and Fologram for Rhino. These plugins, which work integrated with the programs, add various auxiliary functions to the main programs to transfer any designed model to the augmented reality environment. Augin, SketchUp Viewer, Fologram, and Trimble, mobile augmented reality applications used in architectural drawing programs, were examined. The CAD software they work with, their suitability for parametric infrastructure, whether they are open access to public use and their ability to work simultaneously with CAD software was examined. As a result, among these applications, because of containing all the features examined and that the researchers had experienced, Fologram was the preferred use in the study. Fologram [13] is a design application that creates a platform for design and construction in mixed reality. Fologram users include universities, multinational architectural firms, industrial designers, engineers, and artists. The Fologram combines the designed travel setup and the designer's power to represent themself in that space and at its scale and carries it to the same representation layer. The Fologram augmented reality platform can edit geometry, layers, and Grasshopper parameters in real-time on mobile devices and HoloLens. It enables collaborative design in mixed reality, real environment context, and accurate scale. It does not require coding, exporting, or model preparation, making it easier to use in architecture. After downloading the Fologram add-on, users can view the model in the augmented reality environment by scanning the QR code on their mobile devices or mixed reality glasses.

2.1.4 Studies using Fologram applications

Shaghaghian et al. [32], within the scope of a study aimed at improving the spatial design skills of students, a study was carried out to replace the lego pieces in a mixed reality environment with the help of grasshopper parameters with Fologram application. Weissenböck [36] asked students to develop object alternatives for their rooms with the Fologram application in their online lesson due to the Covid-19 pandemic and published the products that emerged from the study.

As can be understood from the above studies, studies using augmented reality applications in interior and architectural education are related to problem detection, obtaining technical information about systems that will create solutions to the problem, determining and creating the system, motivating users, and interoperability of users. In addition, the studies were built on the evaluation of the result with the help of questionnaires and observations.

When all these studies are examined, it is understood that the use of augmented reality in the studio is not questioned based on gender, project level predisposition to use computers, and augmented reality experiences. To reveal these relationships, the field study described below was carried out.

3 Methodology

In this study, it has been tried to reveal the tendency of students who experience these applications in architectural design studio education of augmented reality technologies to the new form of representation through student evaluations. This study focuses on exploring the predisposition of students who experience AR technologies to new representation, gender, course period, familiarity with playing computer games, the effect of computer programs that they can use in their previous augmented reality experience and designs, if any, and the correlation between them has been investigated.

In this context, an architectural design studio process was created in which students' three-dimensional thinking and perception skills are evaluated through software. In the process, students were given an online Rhinoceros course. In this course, Grasshopper, an add-on to Rhinoceros software that allows students to make parametric modelling, and its potentials are also explained (Fig. 5).

The general presentation was given on AR's historical, architectural representation, and augmented reality applications used in CAD. The presentation provided information
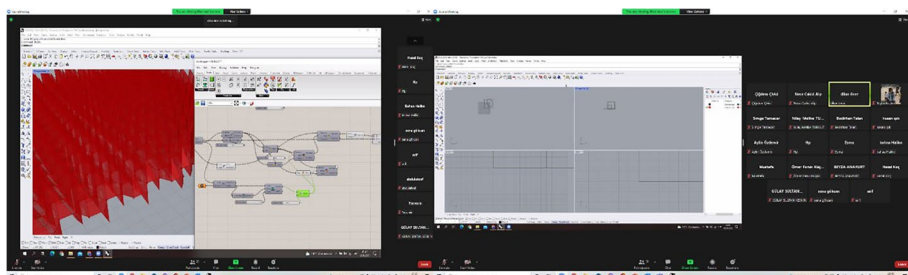

Fig. 5 Rhinoceros and Grasshopper Training

about Fologram, an augmented reality application used in architectural expression, and experiments were conducted via smartphones.

Afterwards, the indoor design problem was given, and they were asked to use Rhinoceros and its add-on grasshopper software under the given design problem. Students were expected to investigate open-source sample Grasshopper scripts and manipulate one of the sample scripts to achieve geometrical patterns.

The indoor design elements developed by the students and various alternatives to these designs were displayed in the real environment with the help of the augmented reality application Fologram. After the final product decision was taken, the students applied a questionnaire to evaluate the workshop process. The questionnaires were analysed with the IBM SPSS Statistics 28 program. The diagram describing the process is in Fig. 6.

3.1 Case study

3.1.1 Student profile

To measure students' predisposition to this new form of representation, a study was carried out within the scope of the Architectural Design Studio at Kocaeli University, Faculty of Architecture, and Design, Department of Architecture.

A total of thirteen students participated in this study, eight females and five males. Students take design courses at three levels, 3 of which are at the 5th level, seven at the 6th level, and three at the 7th level (During the 8-semester architectural education, each student must take a design studio course. So, project-level-3 refers to the 3rd semester's design course education). Considering the frequency of playing computer games, three people played very often, eight people played occasionally, and two never played. Seven students stated that they knew about augmented reality, and 6 of them indicated that they had not heard anything about this subject before this lesson. Considering the computer programs that students use in their designs, 11 of the students Lumion, 11 of them Revit, 8 of them Rhinoceros, 7 of them Grasshopper, 3 of them Vray, 3 of them Illustrator, 1 of them Blender use, and they all use Autocad, Sketchup, and Photoshop (Fig. 7).

3.1.2 Design problem and student works

Students were asked to design indoor exhibition elements to display five models 50×70 cm and five posters in A1 size (54.9×84.1 cm). It is thought that these indoor exhibition elements will be used in the hall where projects are exhibited in Kocaeli University, Department of Architecture. Students were asked to create their indoor design elements using Rhinoceros and its plugin Grasshopper. The designed indoor exhibition elements were transferred to the real environment thanks to the Fologram application working in Rhinoceros. As seen in Fig. 8, where the visuals of student work are included, all students carried out the study by parametrically modelling the exhibition element for the design problem with Rhinoceros and Grasshopper. The students placed the exhibition element they designed using the AR technology Fologram in the given wall space and experienced it in the augmented reality environment.
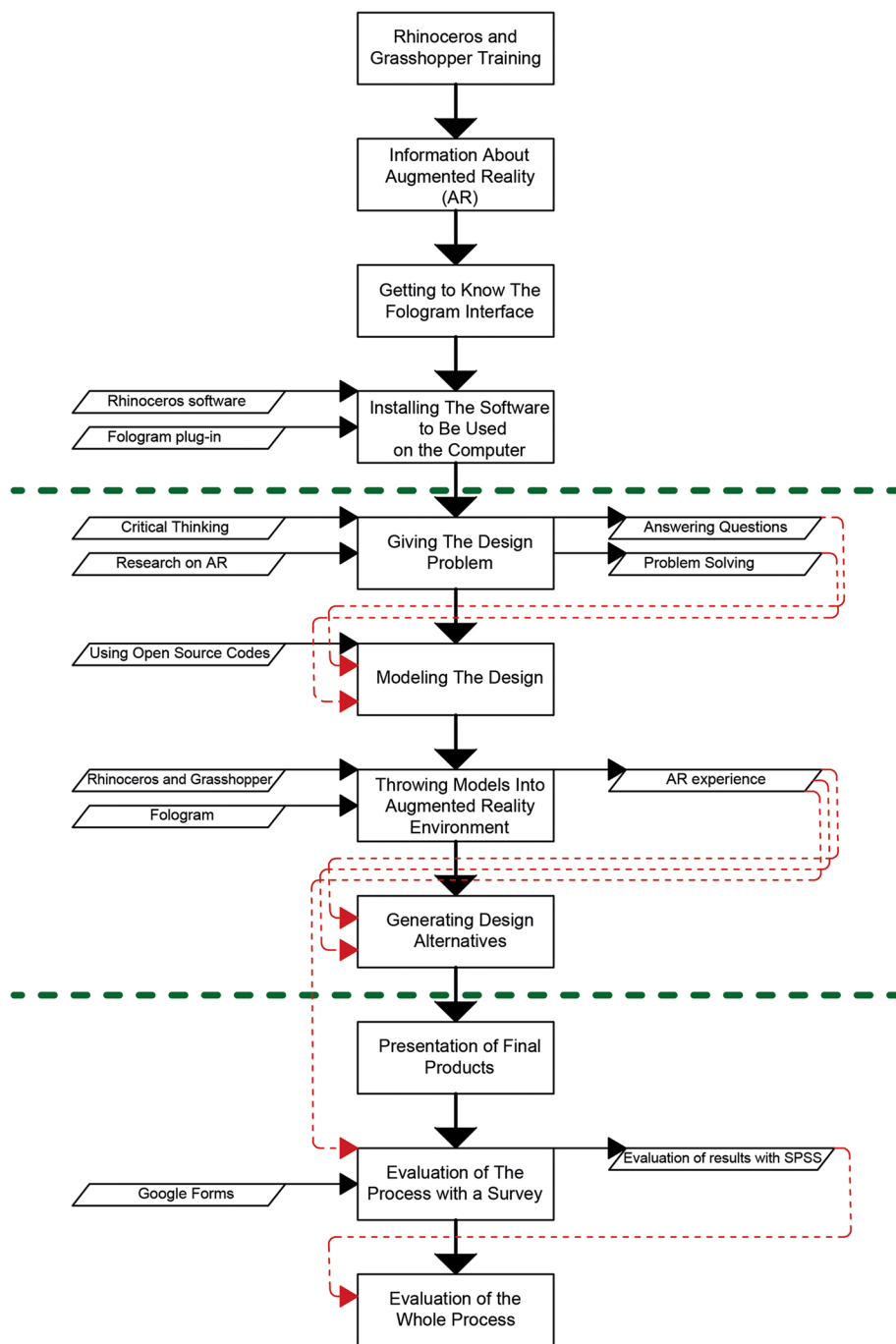
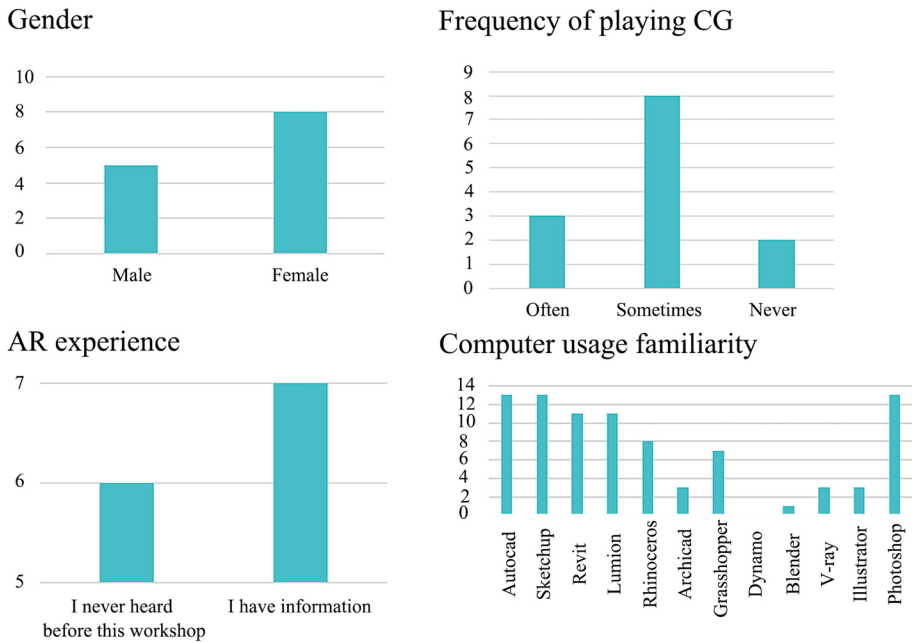**Fig. 6** Flowchart of the steps of the study

Gender

Frequency of playing CG

AR experience

Computer usage familiarity

Fig. 7 Student Profile

3.2 Questionnaire, findings, and discussion

After the study, a questionnaire consisting of five independent and ten dependent variables was applied to the students. In the survey, gender, course level, predisposition to play computer games, the experience of augmented reality, and computer programs that can be used in their designs were included as independent variables. Survey questions consisting of 10 questions are given in Table 1. The Likert scale that responders specify their agreement to a statement is five-point; scored as I strongly agree 5, agree 4, undecided 3, disagree 2, and strongly disagree 1.

A two-tailed Pearson correlation analysis evaluated the relationship between 5 independent and ten dependent variables. SPSS analysis results are given in Table 2.

According to the results of the correlation analysis, three different significant relationships were determined between the variables. Maps can help illustrate connections (or lack of connection) between key stakeholders in a community. Therefore, relationship maps were used to examine the significance between the variables. Relationship maps show how the values of multiple variables relate to each other by visually representing connections and effects through nodes and connections. In this map, nodes represent variables and variable categories, while links show the degree of influence between nodes. The nodes in the figure show the occurrence of coexistence, while the interconnection networks express the frequency of occurrence of interconnected lines. According to this;

- It is seen that there is a significant and robust relationship between gender and the computer programs used by students in their designs. The correlation coefficient was calculated as (r=0.626) (Table 2). When this situation is examined on the relation map, it is understood that the tendency of women to use computers is more intense than men (Fig. 9 a).
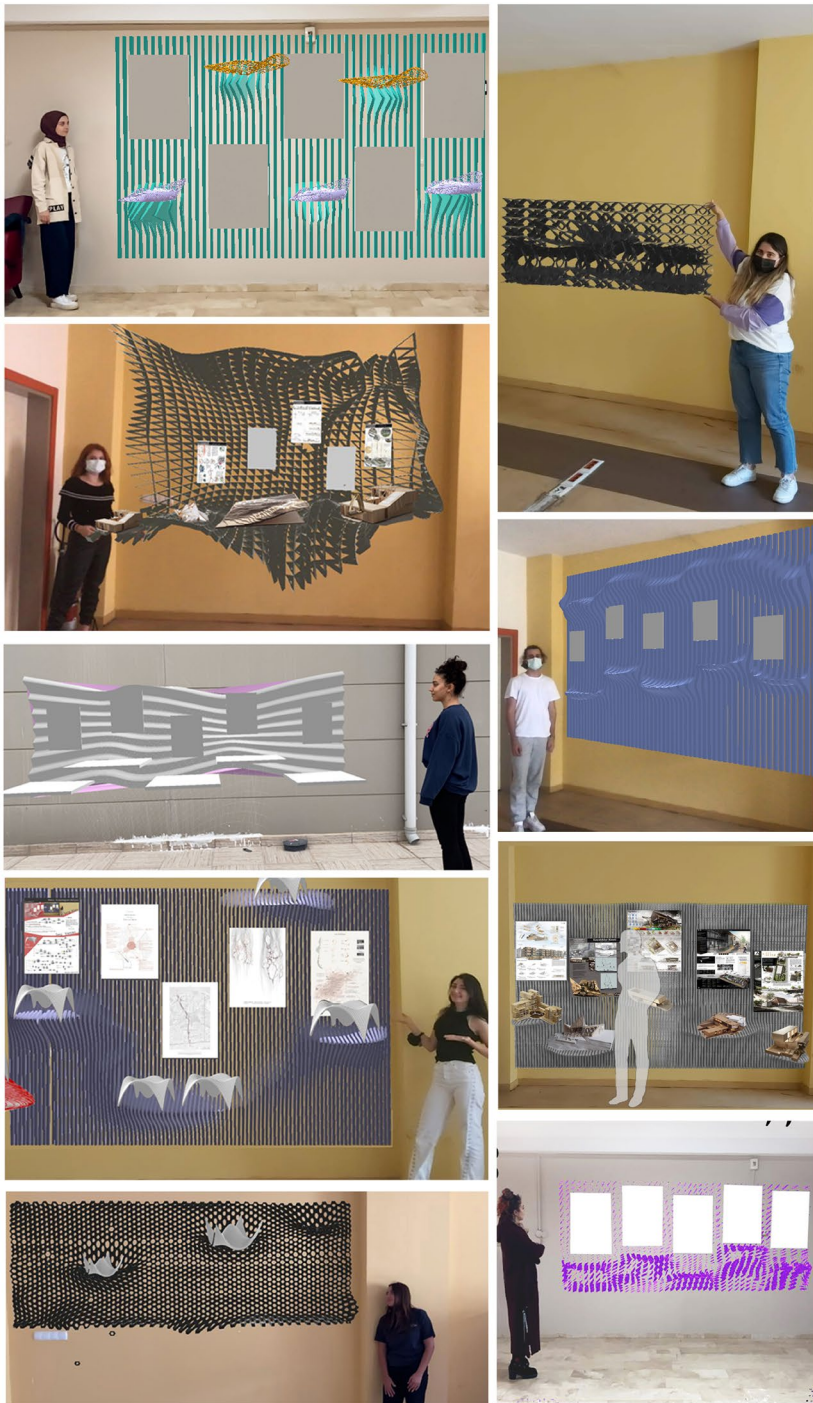
Fig. 8 The augmented reality images from student work

Table 1 Percentages of students answer the questions in the questionnaire

	Questions	Strongly agree %	Agree %	Neither agree nor disagree %	Disagree %	Strongly disagree %
Q1	Using an AR application during architectural design provides simplicity of design	23.1	23.1	30.8	23.1	-
Q2	Using an AR application during architectural design provides the convenience of making changes in the design	30.8	38.5	23.1	-	7.7
Q3	Using an AR application during the architectural design provides the convenience of producing alternatives in the design	23.1	53.8	15.4	7.7	-
Q4	Using an AR application during the architectural design helps to perceive the relation between the designed object and space	46.2	38.5	15.4	-	-
Q5	AR application makes the results of architectural design more realistic	23.1	15.4	53.8	7.7	-
Q6	AR application makes the scale more understandable in the architectural design process	15.4	38.5	15.4	30.8	-
Q7	AR application is suitable for online education	30.8	7.7	23.1	23.1	15.4
Q8	AR application provides a better reflection of design thinking	46.2	30.8	15.4	7.7	-
Q9	AR application increases the designer's design speed	30.8	30.8	23.1	15.4	-
Q10	AR application positively affects the creative idea generation of designers	46.2	30.8	23.1	-	-

Table 2 Correlation analysis results

		a	b	c	d	e	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Gender (a)	Pearson	1	-0,233	0,415	0,415	,626*	0,101	0,399	-0,308	0,101	0,222	-0,136	-0,3	-0,462	-0,128	-0,03
	Sig. (2-tailed)		0,444	0,158		0,022	0,7420	0,177	0,305	0,742	0,465	0,659	0,319	0,112	0,678	0,921
Course Semester (b)	Pearson	-0,233	1	0,000		-0,530	-0,209	0,000	-0,410	-0,157	0,122	0,105	-0,310	-0,239	-0,108	-0,142
	Sig. (2-tailed)	0,444		1,000		0,062	0,493	1,000	0,164	0,609	0,692	0,732	0,32	0,432	0,726	0,644
Frequency of playing CG (c)	Pearson	0,415	0,000	1	0,116	0,32	-0,284	0,245	0,012	-0,227	-0,341	-0,393	-0,184	-0,416	-0,211	-0,036
	Sig. (2-tailed)	0,158	1,000		0,707	0,917	0,347	0,420	0,970	0,457	0,254	0,184	0,546	0,158	0,489	0,907
AR experiment (d)	Pearson	0,415	,681*	0,116	1	0,381	0,395	0,432	0,473	0,395	-0,128	-0,386	0,098	-0,013	0,091	0,074
	Sig. (2-tailed)	0,159	0,010	0,707		0,199	0,182	0,140	0,103	0,0182	0,678	0,193	0,751	0,968	0,769	0,810
Computer usage familarity	Pearson	,626*	-0,530	0,032	0,381	1	,585*	0,479	-0,148	0,252	0,426	0,283	-0,008	-0,284	0,189	-0,119
	Sig. (2-tailed)	0,022	0,062	0,917	0,199		0,036	0,98	0,629	0,406	0,147	0,349	0,979	0,348	0,537	0,699

*, Correlation is significant at the 0.05 level (2-tailed)

- In addition, it was found that there was a strong, negative, and significant relationship between the augmented reality experience and the course level. The correlation coefficient was calculated as (r = -0.681) (Table 2). When this situation is examined in relation map, it can be said that the augmented reality experiences of the students increase as their course levels of the students decrease (Fig. 9b).
- There is a strong, positive, and significant relationship between those who think Using augmented reality application, during architectural design provides simplicity of design and computer usage familiarity. The correlation coefficient was calculated as (r = -0.585) (Table 2). When this situation is examined in relation to maps, it becomes easier for students to use augmented reality in their designs as the level of computer program usage increases (Fig. 9c).

4 Conclusion

This study aims to evaluate the mobile interaction of students who experience augmented reality technologies in the architectural design studio and reveal these effects through students' experiences. By using mobile augmented reality technologies in the study, students' experience of design skills, making changes, producing alternatives, object-space perception, ratio-scale perception, realism (suitability for the real environment), design speed, and creative idea generation were questioned in way of students' gender, project level, computer usage disposition, and augmented reality experience. According to the reviewed literature, there isn't any study in which the mentioned variables are discussed in architectural education using AR applications. It is thought that this study will support this gap in the literature.

Augmented reality is a system that enriches the real environment, thus the human experience, with virtual content. Creating an augmented reality experience environment requires both theoretical and technical knowledge. From the past to the present, hardware and software augmented reality components have changed and developed in the field of informatics. It is envisaged that rapid development in software components, easy accessibility in hardware components, and such studies in architectural education will pave the way for AR to be used more widely in architectural practice, and thus, graduates will gain different perspectives and application skills.

This study was carried out with thirteen students the results obtained from this limited number of samples are valid for this sample group for exploratory purposes and are not generalizable. Results may vary with samples with different numbers and different profiles.

It is thought that this study will contribute to architectural design education and interface design. One of the difficulties experienced by students in architectural design education is that they work in real space but cannot try their designs. With this technology, students will be able to establish a one-to-one relationship with the physical environment from the first stage of their design; thus, the gap between the virtual and physical environment will be eliminated. At the same time, with this study, the interface designers who produce AR technologies will contribute to the prediction of the necessary regulations (user-friendly, etc.) to popularize the use of this technology in architectural education.

This study analytic investigated how augmented reality potentials can be used for architectural and interior design education in the context of students' relevant independent and dependent variables by using survey methodology. Investigating these potentials will determine future educational methodological changes and research directions in this context. In addition, this study can serve as an example for future AR studies in
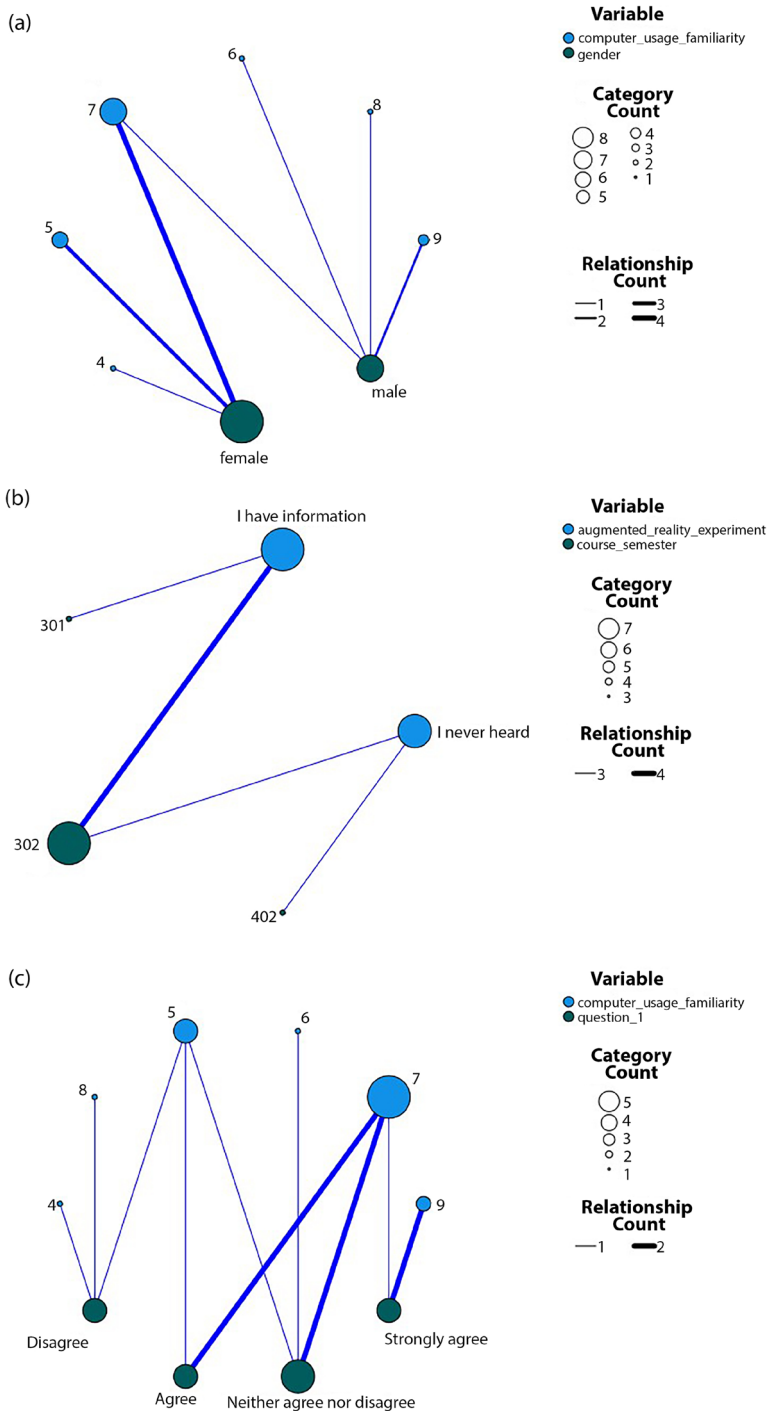
Fig. 9 **a** Relationship map between gender and computer programs used in the design **b** Relationship map between augmented reality experience and course level **c** Q1 and computer programs used in design Relationship map

architectural education. With such a study, it is foreseen that a technology not currently used in architectural design studios can be easily integrated and used.

5 Limitations and Future Vision

This study was carried out with thirteen students because this study was conducted with a group of students who took the design course. However, if such a study is carried out with more people and students with different professional experiences, higher accuracy and more meaningful results can be achieved. The sample data can consist of more and different educational backgrounds for more trustworthy results.

The following research is planned to conduct and analyse another study replicating the augmented reality experience. A new questionnaire based on individual interviews, including qualitative aspects, will be conducted with architectural and interior design students.

Various research can be conducted to measure/compare students' productivity using different immersive technologies and platforms instead of phones. In the future, multiple analyses are foreseen for immersive experiences by moving towards developing other experiences and systems with people in the real environment and with distant collaborators with avatars.

Declarations

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