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Augmented Reality Visualization of Architectural Elements: A Focus on Arches

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***Abstract*—In the few recent years Augmented Reality has become really popular. It is getting attention as an effective way to visualize digital models directly within real-world environments. In architectural education for students who aspire to become architects the students often have a hard time visualizing the complex architectures. The architecture students struggle to understand the architectural components. The traditional teaching method relies heavily only on 2D drawings or static views on screens. This study is about a mobile application that uses augmented reality to help better understand architecture students the complex structural component such as arches. The mobile application is created using Unity to visualize architectural arch models to be visualize as 3D models on mobile devices. Students can explore and learn through the augmented experience by using the application in a more engaging and immersive way. Viewing arch structures at real-world scale helps learners understand how these arch forms function and relate to physical space. The research is about understanding ideas and concepts of system within the context of current AR studies in architecture. The research is about how well the mobile application helps visualize the design and its implementation in the education system. This study shows that the augmented reality based visualization is beneficial, for the students because it helps them to relate abstract architectural concepts to physical space, making learning more intuitive and engaging.**

***Index Terms*—Augmented Reality, Architectural Visualization, Arches, Architectural Education, Unity, Blender**

I. Introduction

Traditionally, architects and students have relied on sketches, physical models, and digital 3D software to develop and communicate design ideas. Although these tools effectively capture fundamental shapes and proportions, they frequently struggle to effectively communicate a genuine sense of scale or spatial depth. For architecture students, this dis-connect often results in difficulty visualizing how a structure will actually appear, scale or function once placed in a real environment.

This limitation is where Augmented Reality (AR) can play a meaningful role. By merging digital enhancements with our real-world environment in real-time, AR enables a precise connection between creativity and actuality [1], [2]. Throughout the past twenty years, the domain has advanced rapidly, propelled by significant improvements in mobile processing capabilities and advanced tracking technologies [3], [4].

Nowadays Augmented Reality has moved beyond the phases, the fact that smartphones and tablets are everywhere these days has really changed things. With smartphones and tablets being so popular it is no surprise that they have had an impact. This has led to some big changes, in the way we live and integrated has these tools directly into educational settings and construction environments [5]. In the realm of architectural education, AR is emerging as a transformative tool for enhancing spatial understanding [6], [7]. Recent re-search indicates that it serves as a link, connecting static digital representations to real-life experiences, which is particularly beneficial during the initial, chaotic phases of the design process [8], [9].

Consider the arch an element that is as structurally vital as it is historically rich. Because arches are geometrically complex and inherently three-dimensional, they are notoriously difficult for students to master through 2D drawings alone. AR offers a way to step inside these forms, making the complex simple by letting students experience the curve and the weight of the design in the space around them. This study explores the use of a Unity-based AR system to visualize architectural arches, aiming to enhance spatial comprehension and learner involvement. The research expands on previous studies in AR-assisted architectural visualization and education [10]–[14], focusing particularly on an in-depth analysis of one architectural element.

II. Fundamentals

Augmented Reality (AR) serves as a link between the physical environment and digital information by overlaying three- dimensional models, textual data, or animations onto a real- time view of the surrounding world. This integration alters the way users perceive and interact with their environment. Since AR systems operate in real time, users are able to interact with virtual objects as though they exist within the physical space. This capability makes AR a particularly effective tool for educational applications and for visualizing complex concepts and structures [1], [9], [16], [20]

A. The Core Components of Augmented Reality

As shown in Fig. 2, that by using a device like a phone or tablet, you can view the real world through its camera and

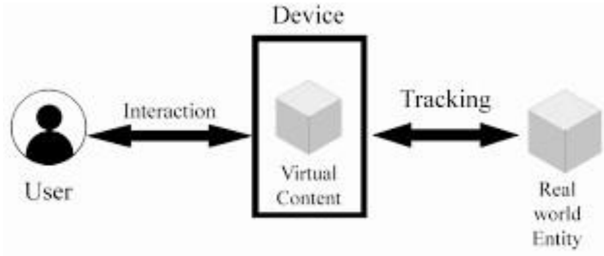

Fig. 1. Augmented Reality Architecture

see virtual objects overlaid on top of it. This allows you to enhance your surroundings with computer-generated visuals and information. An augmented reality system consists of multiple interconnected components that must operate cohesively to provide a stable and realistic user experience [17] Proper integration of these components is essential to ensure accurate alignment between virtual content and the physical environment.

1) Device: The device, typically a smartphone or tablet, serves as the core processing unit, integrating the camera, sensors, and rendering engine to capture real-world data and display augmented content.
2) Real-World Entity: This represents the physical object or environment being observed, such as a printed marker or architectural surface, which the system continuously tracks to determine spatial alignment.
3) Tracking: Tracking computes the position and orientation of the real-world entity relative to the device, ensuring accurate placement and stability of virtual content within the physical environment.
4) Virtual Content: Virtual content includes digital elements such as 3D architectural models and annotations that are rendered and overlaid onto the live camera feed in real time.
5) User Interaction: User interaction is a key component of augmented reality systems. A user interacts with the system by moving the device or using touch gestures, enabling exploration of virtual objects from multiple viewpoints and maintaining a feedback loop.

B. Working Principle of Augmented Reality

The working of an augmented reality system follows a step-by-step process that begins with capturing real-world information and ends with real-time visualization of virtual content.

1) Scene Capture: The process begins when the device camera captures live video of the surrounding environment. These frames are continuously analyzed to detect predefined visual references. In marker-based AR systems, recognizable patterns such as QR codes are used as reference points within the scene [4], [21].
2) Marker Detection and Pose Estimation: Once a marker is detected, the system calculates its position and orientation relative to the camera. This information determines how the virtual object should be aligned within the physical environment.
3) Model Retrieval and Transformation: Based on the detected marker, the corresponding three-dimensional model is loaded. Appropriate transformations, including translation, rotation, and scaling, are applied to ensure accurate placement of the virtual object.
4) Rendering and Integration: The transformed three-dimensional model is rendered and integrated with the live camera feed. This integration occurs in real time, allowing the virtual object to appear naturally within the physical scene.

Using this workflow, the proposed system enables architectural arch models to be visualized directly on printed QR codes. Users can move around the marker and observe the structure from multiple perspectives, supporting improved understanding of architectural form, depth, and spatial relationships.

III. Objectives and Scope of the Study

A. Objectives

This project aims to develop an AR application that helps architecture students visualize architectural arches in real-time, enhancing their structural understanding and design capabilities. By providing an interactive tool, the project addresses common visualization challenges in architectural education, improves spatial awareness, and supports design evaluation. Additionally, it fosters appreciation for cultural heritage by enabling students to explore historical arches through immersive AR experiences. The primary objective of this research is to investigate the use of augmented reality as an interactive visualization tool in architectural education, with particular emphasis on architectural arches. The specific objectives of the study are as follows:

1) To design and develop accurate three-dimensional models of architectural arches using Blender.
2) To develop a Unity-based augmented reality application capable of visualizing architectural models within real-world environments.
3) To implement a marker-based augmented reality approach using QR codes to enable stable and accessible visualization.
4) To enhance students' spatial understanding and perception of architectural forms through interactive AR visualization.
5) To bridge the gap between theoretical architectural concepts and their real-world spatial representation.

B. Scope

The scope of this project is focused on the application of augmented reality to support architectural education, design evaluation, and cultural heritage learning. This project is about using augmented reality to help students learn about architecture evaluate designs and understand heritage. The main goal of the research is to create a tool that lets students play around with arches in a really interactive way. This will help them get a feel for how things fit together in space and make them better, at visualizing structures. Instead of just looking at flat drawings or regular computer models the new approach lets students work with architectural forms in a way that feels more real and easier to understand. Augmented reality is used to make this happen, the project focuses on augmented reality and its application to support education.

The AR tool lets people put three-dimensional arch models right into the space around them and look at them as they are. This way of looking at things lets students try out designs and look at structures from many different angles, which helps them understand how big things are, what shape they are and how they fit together. This is an improvement in the way we study complicated architectural elements like ribbed vaults pointed arches and detailed ornamental forms, which are often not paid much attention to in the usual way of teaching. The AR tool is really good, for learning about these things because it lets students see the models in a more realistic way. The arch models are a part of this process and the AR tool makes it easier to understand them. This system helps students understand the architecture better. The students learn about the design principles that are behind these architectural elements, they gain an understanding of how these elements are structured and how they are designed.

By providing an immersive learning experience, the system helps students connect theoretical architectural concepts with their physical representation in a three-dimensional context. This hands-on learning methodology supports better conceptual clarity and significantly enhances the long-term retention of architectural knowledge. facilitate this, we have outlined a practical, sequential workflow:

Blender: Utilized for creating intricate 3D models. Unity: Utilized to transform these models into an immersive augmented reality experience.

Although the present work focuses on architectural arches, the system has been designed with future expansion in mind. The underlying framework is flexible and can be extended to include additional architectural elements, enhanced interactive functionalities, and even marker-less augmented reality approaches that operate without the need for physical reference markers.

IV. Literature Survey

The literature review examines the use of augmented reality in architecture right now. It talks about how augmented reality's affecting the way we learn, design and think about old buildings and cultural heritage. Augmented reality is being used in architecture to make the visualization of architectural elements better.

A. Introduction

Architectural arches are really beautiful but they can also be very complicated. For students the historical arches can be really tough to understand, this is because they are just looking at 2D flat pictures of arches. The complicated shapes of arches are difficult to visualize from a 2D picture. Traditional pictures and models that do not move are not very helpful for students who want to learn about arches. These arches have a lot of details that students need to see like how the arches are arranged in space and how they are built. Augmented reality is a solution to this problem, it lets students work with 3D models, in real time. Students can really understand what arches are and how they work.

Some people like Kensek who studied this in 2015 think that augmented reality is not something new and fancy. Augmented reality is actually a tool, for looking at spatial concepts. Augmented reality allows students to play around with designs and come up with ideas in a way that feels real and honest. For example, augmented reality does this as we can see in a study [8].

V. Related Work

In the ten years' people have been looking into how augmented reality is used in architecture. Now it is used for many things, for example it helps people see what a building will look like, it also helps with managing construction projects and keeping track of buildings, augmented reality in education even helps teach students who want to be architects. Augmented reality is really changing the way people work in architecture. People are using augmented reality to make their jobs easier and to learn things about architecture.

At the beginning people thought that professional ways of doing things were very important. The idea was easy to understand if you can see something in the world at the same time it is easier to decide if it is the right size and if it is in the right place. As technology got better Augmented Reality became better too. Teachers saw that Augmented Reality is good, for classes where students learn about building design because students need to understand how things fit together in space. When considering the overall perspective, numerous studies have shown that AR consistently enhances students' enthusiasm and it increases motivation and, more critically, improves spatial cognition, which is the mental skill to comprehend and manipulate three-dimensional forms [3], [18]. This journey has not been completely smooth. Researchers have pointed out some problems that are still happening in the world:

Expense, advanced hardware required for the AR can be quite expensive.

Complexity, the technical learning required for the AR tools can be quite complex for both educators and learners.

Logistics is a problem here we have these tools that are really great but it is hard to fit them into the usual academic schedule. The academic schedule is often very set, does not allow for many changes.

Recently, attention has shifted toward the devices we already have in our pockets. Handheld augmented reality that utilizes both "markers" (such as printed codes) and "marker-less" technology (which detects surfaces like floors or walls) has become the preferred method for making these tools more accessible.

Beyond simple visuals, AR is now being used to bring Building Information Modeling (BIM) to life. Instead of squinting at a complex mess of pipes and structural layers on a computer screen, students can see through walls to understand how a building's systems interact [5]. Some researchers are even blending AR and VR to help beginners get a better handle on the absolute basics of architectural form and space [6].

Despite all this progress in big picture visualization and BIM, there is a surprising lack of research on the smaller, fundamental building blocks. Very few studies look at how AR can help students master specific, individual architectural elements like the arch. This is precisely the area our research focuses on, our goal is to address that particular void in the existing literature. This article tackles this deficiency by introducing an AR-driven visualization system tailored for the study and examination of arch structures.

VI. System Architecture and Implementation

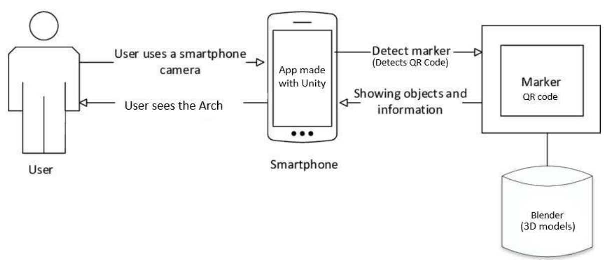

Fig. 2. System Architecture

A. 3D Model Development Using Blender

Blender [20] is a program that helps people make 3D pictures, visual effects, games and more on their computer, it is free to use. It is used for a lot of things like making 3D models, animations and even games. The Blender was used to make models of arches. When the models were made it was made sure to get all the details right like how big they were and the shape of the curve so the arches would look like real arches. It was important that these models of arches to work well on devices. So it was made sure that the models of arches did not have many polygons, the materials and textures to the models of arches were added. The boundaries and pivot points for the models of arches were set. This way people can turn the models of arches and see them from different sides. The program Blender was really helpful in making these models of arches. When finished making the models of arches the models were exported in FBX format. This made it easy to put the models of arches, into Unity. The models still had all the details, like the shape and the materials when they were imported into Unity.

B. Unity-Based Application Development

Unity [19] is a popular platform that supports creation of augmented reality applications. The primary tool for this within the platform is Unity's AR Foundation, a cross-platform framework that allows developers to build AR experiences for both Android and iOS from a single codebase. Unity, alongside AR Foundation was used to make the AR application. The models were imported from Blender. Then the scenes were set up so that the application could use marker-based tracking and render things in real time. The lighting was set up in ways to make the models look more real and to help people see how detailed arches. To make sure the application worked well on mobile devices some things were done to make it run more smoothly like compressing the textures and adjusting the level of detail. Unity is really good at working with different platforms. This means that Unity can work with Android devices and iOS devices. Unity makes sure that things are compatible, with both Android and iOS. So you can use Unity with Android and iOS devices.

C. Marker-Based AR Visualization

Marker-based augmented reality relies on printed markers to align virtual things in the real world. These markers have patterns that only a camera on a device can see and understand. The markers are QR codes, logos or special pictures that are printed on paper or put on objects. When the system finds a marker it puts a three-dimensional model of an architectural arch on top of the marker right away. People can walk around the marker, can view the model, from many different sides. This helps them understand how things are laid out in space what the building looks like and how the different parts line up. The system lets users play around with the building so they can see how all the parts of a building fit together in a real space, which makes it easier for them to understand how things work in a physical space and that really helps with understanding spaces. In addition to basic visualization, the proposed system incorporates several additional features to improve usability and learning effectiveness:

- Detection of Multiple Markers: The system can show many QR codes all at the same time. This makes it easy to compare architectural styles, like modern and old right next to each other. The system is really good at identifying QR codes and displaying them together.
- User Interaction: People can view the models by touching the screen to take a look at specific parts or move the handset.
- Monitoring Performance: The system keeps an eye on how the frames are moving and how well the model is being projected to make sure the live rendering is done smoothly in real time. The models and the system work together to provide an augmented experience, for users.

This approach establishes a strong and engaging AR setting by integrating precise 3D modeling, live rendering in Unity, and effective marker-based deployment, which makes it very appropriate for architectural learning and discovery.

VII. Results

A. Marker Detection

The performance of marker detection was assessed using five different smartphone models to consider variations in hardware capabilities. The detection times varied between approximately 0.4 seconds and 1.5 seconds, depending on the specific device. In typical indoor lighting, the system attained a detection accuracy exceeding 90 percent when the distance between the camera and the marker was kept between 15 cm and 50 cm. These findings suggest that the marker-based method is dependable for classroom settings and demonstrates consistent performance across widely available mobile devices.

B. Learning Outcomes

The evaluation of student learning outcomes was conducted through pre- and post-assessment scores to assess students' conceptual understanding prior to and following their interaction with the AR system. The study found that students understood geometry, architectural typology and structural behavior a lot better, they did 27 percent to 34 percent better. This means the system really helped students learn about principles because it was interactive and immersive.

The results show that using this method that is based on augmented reality is really good, for education. It helps students learn about architecture in an immersive way. The method makes a difference and students learn more when they use it to study arch geometry, architectural typology and structural behavior.

C. Discussion

During the initial evaluation stage, the augmented reality application was implemented on a standard mobile device and assessed within a typical classroom setting. The system underwent testing under normal lighting and usage scenarios to accurately represent how it would function during real teaching sessions. When the device's camera focused on a printed QR marker, the relevant architectural arch model successfully appeared on the screen, indicating effective marker detection and model visualization.

There was a delay when the application started up. It took about 0.4 to 1.5 seconds. The application startup delay happened because the system had to find the marker load the three-dimensional model and start the rendering function.

The application startup delay was not a deal, from an educational standpoint. This brief pause was okay. It did not stop people from being engaged in the classroom or participating. The application startup delay was acceptable.

When the model was shown it worked well all the time. The virtual arch stayed in the place even when people moved around the marker or looked at it from different angles. This was very important for keeping people interested because it let students move around and look at the structure from different sides. When students can walk around and look at something from angles they can understand things, like how big it is, what shape it is and how different parts fit together. These are things that can be hard to understand when you are just looking at a flat 2D picture. When people move around a space they get an idea of how big things are and how they fit together. They understand the space better because they can see the depth and the structure of it. This is something that can be difficult to see in 2D pictures. The space feels more real when you can walk around it. You can see how everything is connected and how it is all put together. Moving through the space helps learners understand the scale and the structure of it.

Using a marker-based approach for Augmented Reality turned out to be a smart move. It is budget-friendly because Augmented Reality does not require any gear it is a practical choice for classrooms. Classrooms often do not have access to high-tech equipment. This approach makes advanced 3D visualization accessible to about anyone with a standard mobile device.

At the same time, a few limitations were observed during system use. Changes in lighting conditions occasionally affected marker detection accuracy, especially in environments when the lighting changed, if a room was too dim or had harsh, uneven shadows.

In the end, the results show that marker-based AR is a solid, effective tool for teaching architecture. It creates an engaging, hands-on learning environment while giving us opportunities for future improvements, particularly in enhancing robustness under varying lighting conditions and improving performance across a wider range of devices.

VIII. Conclusion

This paper is, about a system that uses markers to make Augmented Reality work. The system helps students learn about arches in an interactive way. They can use their mobile devices to see the arches in real time. The people who made this system used a program called Blender to make models. Then they used Unity to build the Augmented Reality application, this application with AR foundation can track markers. When students scan a marker they can see detailed 3D models of different types of arches. They can interact with these arches. Learn more about them. The results show that the 3D models shown are clear. They are geometrically accurate which helps students understand complex architectural forms better.

The system puts structures in the real world so it helps connect what students learn in theory to what they can actually see which is a big help for students to understand architectural forms and the 3D models. The intricate arch designs that are important in history help students learn about the culture behind architecture. This way students can understand where these buildings come from while they are learning about how they are made. The system works well on mobile devices. This makes it easy for people to use whether they are in a classroom, a lab or studying on their own. The arch designs are a part of this system and mobile devices make it easy to access the arch designs and learn from them.

In summary, this marker-based AR system is a practical and effective educational tool. It transforms traditional teaching into an immersive, interactive experience and has strong potential for integration into academic curriculum, digital preservation efforts, and future AR-based learning environments.

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