

Implementation of Hybrid 2D-3D Multilayer Visualization for Marker-Based Augmented Reality Learning Media

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Abstract – Marker-based Augmented Reality (AR) has been widely adopted in educational media due to its ability to present interactive digital content in real-world environments. However, most AR learning applications primarily emphasize standalone three-dimensional (3D) objects with limited integration of supporting visual elements. This study explores the implementation of Hybrid 2D–3D Multilayer Visualization for marker-based augmented reality learning media by integrating multiple two-dimensional (2D) decorative layers with interactive 3D learning objects. The application was developed using Unity and the Vuforia Engine, while 2D visual assets, including the image marker and decorative layers, were designed using Canva, and animated 3D objects were obtained from Sketchfab. Functional evaluation was conducted using the Black Box Testing method to verify the system's performance. The results show that all application functionalities, including marker recognition, visualization rendering, animation playback, and marker tracking, operated successfully according to the specified requirements. The implementation demonstrates that Hybrid 2D–3D Multilayer Visualization provides a structured and visually enriched marker-based AR environment, serving as a practical reference for developing interactive educational media.

Keywords: 2 Dimension, 3 Dimension, Multilayer, Augmented Reality

I. Introduction

Augmented Reality (AR) has become one of the emerging technologies in educational media due to its capability to seamlessly integrate virtual content into real-world environments [1], [2]. By combining digital information with physical objects, AR provides interactive and immersive learning experiences that enhance students' engagement [3], motivation [4], and conceptual understanding [5]. Among various AR approaches, marker-based augmented reality remains widely adopted in educational applications because of its stable object tracking, ease of implementation, and compatibility with mobile devices [6].

Recent studies have demonstrated the effectiveness of AR in improving learning outcomes across various educational domains [7], [8]. In particular, marker-based AR enables students to visualize abstract concepts through interactive three-dimensional (3D) models while maintaining the context of printed learning materials. However, most educational AR applications primarily focus on presenting standalone 3D objects, with limited attention given to the organization and integration of supporting visual elements within the AR scene.

Several studies have investigated the role of two-

dimensional (2D) and three-dimensional (3D) interfaces in AR environments. A comparative study on 2D and 3D user interfaces reported that 3D interfaces significantly reduced users' cognitive load and improved perceived usability compared with conventional 2D interfaces during repetitive AR tasks. These findings indicate that the selection and arrangement of visual elements directly influence users' interaction quality and learning experience [9].

In educational applications, 2D AR has also been integrated into digital learning media. For example, a physics e-worksheet incorporating 2D augmented reality demonstrated significant improvements in students' mathematical representation abilities while achieving high feasibility for classroom implementation [10].

These studies demonstrate that both two-dimensional (2D) and three-dimensional (3D) visual representations play important roles in augmented reality applications. Previous research has mainly focused on comparing 2D and 3D interfaces, evaluating their effects on usability and cognitive load, or developing learning media using either 2D or 3D visualization independently. In addition, studies on hybrid and multilayer visualization have primarily been conducted in visualization and geographic information systems, where layered visual representations are used to

improve information presentation rather than educational marker-based AR applications. Consequently, limited research has investigated how multiple 2D decorative layers can be technically integrated with interactive 3D learning objects in a single marker-based augmented reality environment.

Therefore, this study explores the implementation of Hybrid 2D–3D Multilayer Visualization for marker-based augmented reality learning media. Instead of proposing a new visualization model or algorithm, this work focuses on documenting the technical implementation process, including asset preparation, marker registration, multilayer scene composition, and visualization integration using Unity and the Vuforia Engine. The primary contribution of this paper is to provide a practical implementation reference that demonstrates how multiple 2D decorative layers and animated 3D learning objects can be effectively integrated into a marker-based AR learning application, thereby complementing previous studies that have mainly examined 2D and 3D visualization separately.

II. Methodology

This study adopted a development-based approach to implement Hybrid 2D–3D Multilayer Visualization for marker-based augmented reality learning media. The development process consisted of three phases: pre-production, production, and post-production [11], as illustrated in Fig. 1.

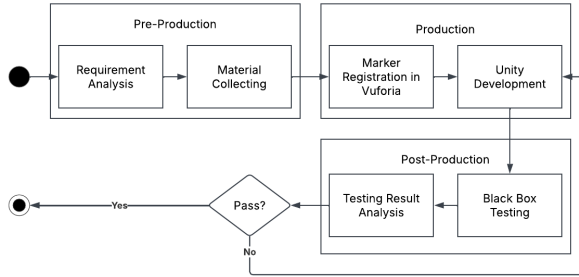


Fig. 1. Research Stage

The pre-production phase focused on planning and preparing the materials required for the augmented reality application. Requirement analysis was first conducted to determine the learning objectives, visualization concept, application flow, and marker-based interaction. Subsequently, visual assets were collected and prepared. Two-dimensional (2D) assets, including the image marker, background, and four decorative layers, were designed using Canva. The image marker was designed with high visual contrast and distinctive feature points to achieve reliable recognition by the Vuforia Engine. Meanwhile, four animated three-dimensional (3D) learning objects (fish, sailfish, turtle, and shark) were obtained from Sketchfab. The selected models fulfilled several criteria, including free availability, compatible file format (.fbx/.obj), animation support, educational relevance, and compatibility with Unity.

The production phase involved implementing the prepared assets into the marker-based augmented reality environment. The image marker was uploaded to the Vuforia Target Manager, where it was analyzed to generate feature points and image target data. Only markers achieving a five-star Augmentable Rating were used to ensure stable detection and tracking performance. The generated database was then imported into Unity 2022.3.62f3, together with the prepared 2D decorative layers and animated 3D learning objects. Subsequently, the Hybrid 2D–3D Multilayer Visualization was implemented by arranging the four decorative layers behind and around the interactive 3D objects to create visual depth while maintaining the visibility of the educational content.

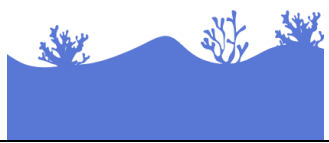
The post-production phase consisted of functional evaluation using the Black Box Testing method. The developed application was built using Unity 2022.3.39f1 and exported as an Android Package (APK) before being installed on a Redmi 13 smartphone equipped with a MediaTek Helio G91-Ultra octa-core processor and 8 GB of RAM. Functional testing was conducted in the actual operating environment to verify that every system function operated according to the specified requirements. The evaluated functionalities included application initialization, marker recognition, rendering of the Hybrid 2D–3D Multilayer Visualization, animation playback of each 3D object, marker tracking, navigation, and visualization recovery after marker re-detection. The observed system behavior was compared with the expected outputs to assess the correctness and reliability of the developed marker-based augmented reality learning media.

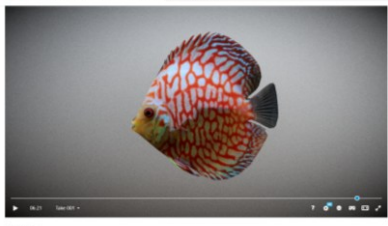
III. Result and Discussion

A. Material Collecting

The material collecting stage focused on preparing both two-dimensional (2D) and three-dimensional (3D) assets required for implementing the Hybrid 2D–3D Multilayer Visualization. The 2D visual assets were designed using Canva and consisted of an image marker along with four decorative layers that create visual depth and contextual representation within the augmented reality environment. The image marker serves as the tracking target for marker-based augmented reality, while the decorative layers function as supporting visual elements surrounding the primary learning content. The 3D learning assets were obtained from Sketchfab, utilizing freely available animated models. Each model was selected according to the learning content and optimized before being integrated into the Unity environment. The complete list of visual assets used in this study is presented in Table I.

TABLE I
VISUAL ASSETS USED IN HYBRID 2D–3D MULTILAYER VISUALIZATION

Type	Visualization	Source
2D Layer		Canva
		
		
		
Marker		
3D Object		Sketchfab

Type	Visualization	Source
		
		
		

B. Marker Implementation

The marker implementation was carried out using the Vuforia Engine by first registering the designed image marker in the Vuforia Target Manager. The uploaded marker was analyzed to generate feature points for image recognition and tracking. As shown in Fig. 2, the marker achieved an Augmentable Rating of five stars, indicating that it contains sufficient distinctive visual features for reliable detection and stable tracking in the marker-based augmented reality environment.

After the marker database was successfully generated, it was downloaded from the Vuforia Target Manager and imported into the Unity project. The imported database was then activated through the Vuforia configuration, allowing the image target to be recognized and called within the Unity scene. Once the marker was detected by the device camera, the Hybrid 2D–3D Multilayer Visualization, including the decorative 2D layers and interactive 3D learning objects, was rendered in real time.

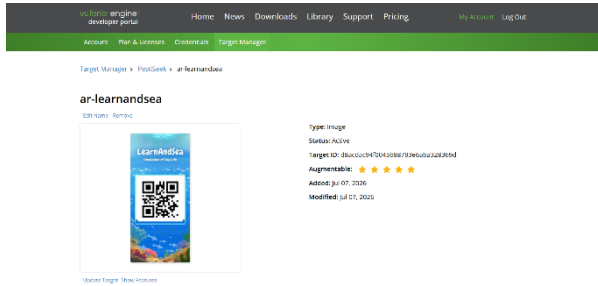


Fig. 2. Image marker uploaded to the Vuforia Target Manager with a five-star Augmentable Rating.

C. Augmented Reality Implementation

The augmented reality implementation was performed in Unity by integrating the marker database generated from the Vuforia Engine with the prepared visual assets. As illustrated in Fig. 3, the Hybrid 2D–3D Multilayer Visualization was organized into multiple layers, where each decorative 2D ornament was paired with a corresponding interactive 3D learning object. The arrangement consists of Ornament 1 – Turtle, Ornament 2 – Sailfish, Ornament 3 – Fish, and Ornament 4 – Shark, creating a structured visualization that combines decorative elements with educational content within a single marker-based AR scene.

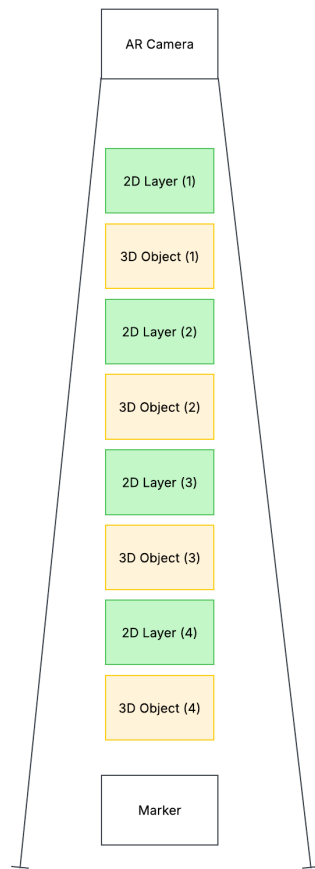


Fig. 3. Hybrid 2D–3D Multilayer Visualization Structure

The implementation results of the marker-based

augmented reality application are presented from three viewing perspectives, as shown in Figs. 4–6. Fig. 4 illustrates the left-side view of the Hybrid 2D–3D Multilayer Visualization, highlighting the arrangement of decorative 2D layers and the corresponding 3D learning objects. Fig. 5 presents the front (center) view, showing the overall composition of the integrated visualization. Fig. 6 depicts the right-side view, demonstrating the spatial arrangement and depth created by combining multiple 2D decorative layers with interactive 3D objects within the augmented reality scene.

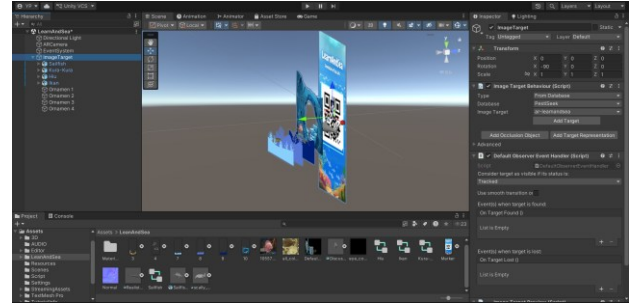


Fig. 4. Right-side view of the Hybrid 2D–3D Multilayer Visualization.



Fig. 5. Front view of the Hybrid 2D–3D Multilayer Visualization.

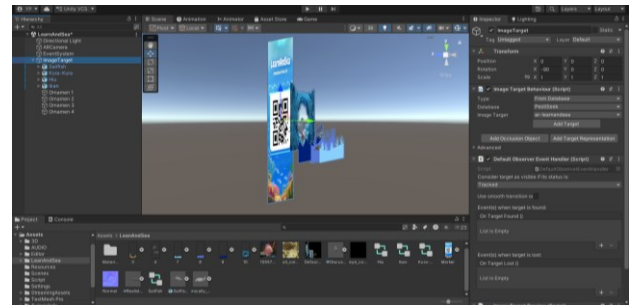


Fig. 6. Left-side view of the Hybrid 2D–3D Multilayer Visualization.

D. Black Box Testing

Black Box Testing was conducted to evaluate the functional performance of the developed marker-based augmented reality learning media. This testing method verifies whether each system function operates according to the specified functional requirements without considering the internal source code [12]. The evaluation covered the main functionalities of the application,

including application initialization, marker recognition, visualization of the Hybrid 2D–3D Multilayer Visualization, rendering of the 3D learning objects, animation playback, marker tracking, and visualization recovery. The detailed testing scenarios and expected results are presented in Table II.

TABLE II
BLACK BOX TESTING SCENARIOS

No.	Test Scenario	Expected Result	Status
1	Launch the application	The application starts successfully and displays the main interface.	Pass
2	Open the AR camera	The AR camera is activated and ready to detect the marker.	Pass
3	Detect the image marker	The marker is successfully recognized by the camera.	Pass
4	Display the Hybrid 2D–3D Multilayer Visualization	Four 2D decorative layers and all 3D learning objects are displayed correctly.	Pass
5	Display the Turtle object	The Turtle model appears in the correct position on the marker.	Pass
6	Play Turtle animation	The Turtle swimming animation is played automatically.	Pass
7	Display the Sailfish object	The Sailfish model appears correctly on the marker.	Pass
8	Play Sailfish animation	The Sailfish swimming animation is played automatically.	Pass
9	Display the Fish object	The Fish model appears correctly on the marker.	Pass
10	Play Fish animation	The Fish swimming animation is played automatically.	Pass
11	Display the Shark object	The Shark model appears correctly on the marker.	Pass
12	Play Shark animation	The Shark swimming animation is played automatically.	Pass
13	Move the marker	All 2D layers and 3D objects continuously follow the marker position without misalignment.	Pass
14	Remove the marker from the camera view	All AR objects disappear when the marker is no longer detected.	Pass
15	Re-detect the marker	The AR visualization is rendered again correctly after the marker is detected.	Pass

Based on the Black Box Testing results presented in Table II, all testing scenarios were successfully executed, indicating that every functional component of the marker-based augmented reality application operated as expected. The application successfully recognized the image marker, rendered the Hybrid 2D–3D Multilayer Visualization, displayed all interactive 3D learning objects together with their animations, and maintained stable tracking during marker movement. Furthermore, the visualization was successfully restored after the marker was re-detected. The functional testing process is illustrated in Fig. 7, which shows the application running in the Unity development environment, while the deployment and execution of the exported Android application on a Redmi 13 smartphone are presented in Fig. 8. These results confirm that the developed marker-based augmented reality learning media performs reliably

in both the development and actual mobile execution environments.

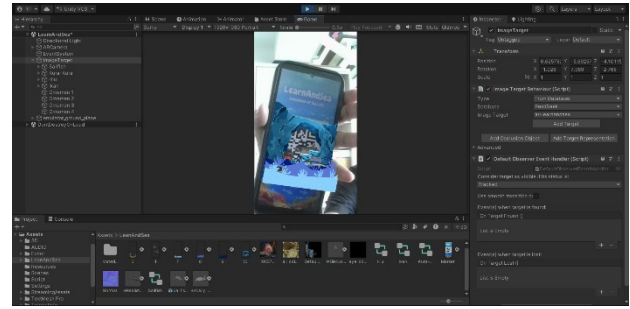


Fig. 7. Functional testing of the Hybrid 2D–3D Multilayer Visualization in the Unity development environment.

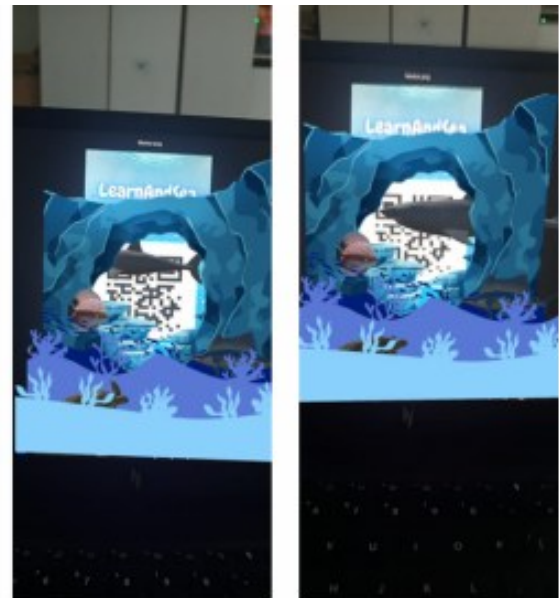


Fig. 8. Functional testing of the exported Android application on a Redmi 13 smartphone.

E. Discussion

This study aimed to explore the technical implementation of Hybrid 2D–3D Multilayer Visualization in marker-based augmented reality learning media by integrating multiple two-dimensional decorative layers with interactive three-dimensional learning objects within a single AR environment. The implementation results demonstrate that the proposed visualization was successfully developed using Unity and the Vuforia Engine. The application was capable of recognizing the image marker, rendering four decorative 2D layers, displaying four animated 3D learning objects, and maintaining stable visualization throughout marker tracking. These findings indicate that the implementation objective defined in this study was successfully achieved.

The integration of multiple 2D visual layers with 3D learning objects provides a more structured visual presentation than displaying standalone 3D objects. The decorative layers create contextual environmental

elements that enhance visual depth while preserving the visibility of the primary educational content. This layered arrangement enables supporting visual information to coexist with interactive 3D objects without interfering with marker recognition or object rendering. From a technical perspective, the implementation demonstrates that combining heterogeneous visual assets within a marker-based AR scene can be achieved efficiently using Unity and Vuforia while maintaining stable real-time performance.

The findings are consistent with previous studies emphasizing the importance of visual representation in augmented reality. The comparative study by [9] reported that three-dimensional interfaces provide better usability and lower cognitive load than purely two-dimensional interfaces, highlighting the significance of effective visual presentation in AR environments. Meanwhile, the educational AR study presented in [10] demonstrated that two-dimensional AR learning media can improve learning effectiveness through well-designed visual content. Unlike these previous works, which primarily evaluated either 2D or 3D visualization independently, this study focuses on the practical implementation of integrating multiple 2D decorative layers with animated 3D learning objects into a unified marker-based augmented reality scene. Therefore, this work contributes an implementation reference for developers seeking to combine hybrid visual elements in educational AR applications.

Overall, the successful implementation and functional validation indicate that the proposed Hybrid 2D–3D Multilayer Visualization can effectively support the development of marker-based augmented reality learning media. The Black Box Testing results confirmed that all functional requirements, including marker recognition, multilayer visualization rendering, object animation, and marker tracking, operated as expected. However, the scope of this study is limited to technical implementation and functional evaluation. User-centered evaluations, such as usability testing, user experience assessment and learning effectiveness measurement, were not conducted and therefore fell outside the scope of the present work. Future research may extend this implementation by conducting empirical studies involving learners to investigate the impact of the proposed visualization on usability, user experience, cognitive load, and learning outcomes.

IV. Conclusion

This study explored the implementation of Hybrid 2D–3D Multilayer Visualization for marker-based augmented reality learning media by integrating multiple two-dimensional decorative layers with interactive three-dimensional learning objects into a single AR environment. The implementation was successfully developed using Unity and the Vuforia Engine, while visual assets were prepared using Canva and Sketchfab. Functional evaluation through Black Box Testing confirmed that all application features.

The findings demonstrate that the integration of hybrid 2D and 3D visual elements can provide a structured and visually enriched marker-based augmented reality environment without compromising system functionality. This implementation serves as a practical reference for the development of educational AR applications that require the combination of decorative visual components and interactive 3D content. Future work may extend this study by evaluating the effects of Hybrid 2D–3D Multilayer Visualization on user experience, cognitive load, and learning outcomes.

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