Assessing the user experience of marker-based 3D WebAR applications using user experience questionnaire

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ABSTRACT

Marker-based 3D web-based augmented reality (WebAR) applications are an emerging field that merges web technologies with augmented reality. WebAR has gained popularity because of its ability to provide users with a reliable and autonomous platform. Yet, a limited investigation has verified its application and user perspective on its ability to function. This study is designed to evaluate the user experiences of marker-based 3D WebAR applications using the user experience questionnaire (UEQ). This study assesses various elements of the user experience, including attractiveness, clarity, engagement, efficiency, and innovation, utilizing the UEQ. This study aims to analyze user perceptions and interaction patterns thoroughly to get useful insights into the usability and user satisfaction aspects of marker-based 3D WebAR apps. The findings reveal that the WebAR app is both appealing and efficient, instilling confidence in its users. This underscores the pivotal role of user experience in shaping the effectiveness and reception of WebAR applications. This research has the potential to influence the creation of more user-focused and engaging marker-based 3D WebAR experiences, improving user engagement and immersion in web-based augmented reality environments.

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1. INTRODUCTION

Augmented reality (AR) is a technology that brings together the virtual and physical worlds on a similar platform. The technology of AR will enable real-time integration of digital material (images, video, and animation) with the user's surroundings, resulting in a combination of materials or augmented vision [1], [2]. The enriching information presented through AR helps to enhance interaction between the user and the subject. To date, AR has diverse applications in a range of industries, indicating its versatility and potential impact on several organizations. For example, the massive success of games like Pokémon GO, which utilizes smartphone displays to project imaginary animals into the real world, is proof that AR is being used to provide more immersive and engaging learning experiences by visualizing difficult ideas or historical events.

AR technology is normally applied through mobile applications (known as mobile AR) and web-based AR applications (WebAR). WebAR is a digital technology that allows clients to conveniently access augmented reality experiences online, without requiring specialist software [3]. The literature reveals a number of AR applications that are useful in understanding individuals' perceptions of adopting the technology, particularly for cultural tourism [4], education [5], and marketing [6]. Among them, WebAR was not a popular implementation platform compared to mobile AR. It could be due to the rapid evolution of technology, which requires a change in the user's perspective, different requirements for platform capabilities [7], 3D rendering method [8], more exploration of architecture, platforms, codes, and adaptation of the environment [3]. Furthermore, web AR is one of the technologies that could lead to better experiences and higher-quality instruction in a variety of contexts outside of educational institutions [9].

In general, the fundamental ideas of AR and WebAR for augmenting related content remain the same. The differences between WebAR and mobile AR lie in the architecture and operability of AR. The implementation of WebAR will use the available JavaScript library and API [7]. However, there will be a limitation when the library or API is not supported. Thus, more libraries have to be created for those purposes. WebAR implementation can be considered to be less expensive, lightweight, and easy to use. This is because WebAR's idea streamlines the augmented reality experience by eliminating the need for app downloads, which were previously a barrier to using augmented reality on mobile devices. Instead, users can now view augmented reality elements directly in their web browser. Users can quickly engage with the latest digital experiences by simply visiting a designated URL, such as animating a product label or showcasing an interactive product demo on a business card. Moreover, the implementation of WebAR may or may not have a subscription cost, depending on the requirements of the developer or publisher. The application is web-based, so its primary constraint may be network dependency [3]. If the internet connection is in bad shape, it will have an impact on loading and streaming, which in turn may adversely affect user experiences.

The goal of AR is to create a more enriched and interactive user experience by seamlessly blending the digital and physical worlds [10]. The AR element can be projected according to the type of AR, either marker-based or markerless. A marker-based system uses physical markers such as photographs, QR codes, and objects to activate and secure the augmented reality virtual content inside the actual world [11]. These markers provide guide points for the augmented reality system as it superimposes digital data onto the user's visual experience captured by the camera of their device [5], [12]. Unlike markerless AR, the projection of virtual material does not rely on the use of specific physical markers. Instead, computer vision algorithms, sensors, and ambient characteristics are employed to observe the user's environment and position AR components inside the physical world [11]. According to research by Brito and Stoyanova [11], marker-based augmented reality (AR) has a more positive effect on user experiences compared to markerless AR. This finding is based on several aspects, such as emotional characteristics, the adoption of innovative technology, and familiarity with the brand. Furthermore, a study conducted by Basiratzadeh *et al.* [12] contends that markerless systems exhibit a diminished level of precision and may not be well-suited for real-time applications. In contrast, marker-based systems offer a steady and immediately recognizable pattern. The selection between marker-based and markerless AR hinges upon the particular demands of the application and the intended user experience. Some apps may utilize a blend of both approaches in order to enhance the user experience.

This study investigated the effect of WebAR on user experiences. While earlier studies have explored the impact of AR applications in various contexts, they have not explicitly addressed its influence on user experience since the measurement tools they used are different and more suitable to the context of the study. For example, a study conducted by Dutta *et al.* [13] examined the usability of two mobile AR applications, one based on key input and the other based on markers. The study assessed usability using the system usability score (SUS) and the handheld augmented reality usability score (HARUS) models. In the study, mobile augmented reality (MAR) applications serve as an educational tool for instructing students about Karnaugh mathematics. The findings of the study demonstrate that the key-based approach has yielded better user engagement than the marker-based MAR application. Meanwhile, a study conducted by [14] used AR technology as a tool for children to learn about mosquitoes and dengue. They also used UEQ to evaluate users' impression of the AR application, and the outcome from UEQ suggested a positive usage of AR in assisting student's understanding of learning. However, they only achieved two user experience elements: attractiveness and stimulation. In contrast, a study by Ribeiro *et al.* [15] explored the potential user requirements for real-time AR applications in drone pilot training through usability testing. The results suggest that AR application usability can be achieved using web technologies, which offer high availability by leveraging the web and other widely accessible platforms. However, while numerous studies on AR applications have shown promising results, the development of WebAR applications is still in its infancy. The performance of the WebAR application is regarded as an effective and successful solution for meeting customer needs and increasing productivity [7]. This promising stage highlights the need for ongoing assessment of their usability to ensure these technologies can gain widespread acceptance among users.

This study aims to assess the effectiveness of WebAR by developing a marker-based WebAR application. Additionally, it seeks to analyze the user's acceptance and usability of WebAR during real-time events. A specific WebAR application that overlays 3D content on the material was developed for the purpose of this study. The results showed that the user's acceptability and usability considerably favorably impact them. Thus, the result will contribute to the usability of marker-based 3D WebAR applications. This paper is organized as follows: section 2 provides information on the methodology and resources used in this study. The results are then presented in section 3, which also includes a discussion of key findings and the work's limitations. Finally, section 4 concludes the research project as well as the plan for future work.

2. METHOD

This section comprehensively explains the methodology and resources used in this study. The description includes the development tools and materials for marker-based 3D WebAR and the assessment tools and materials used for the same purpose. Additionally, a step-by-step explanation of the study's methodology is provided.

2.1. Methodology

This study adopted the rapid application development (RAD) technique to create the WebAR application from development to evaluation. RAD was selected for its methodology, which emphasizes creating the application quickly through rapid development and iteration methods. These procedures will expedite system delivery by utilizing prototypes and reusing code. RAD has proven to be a valuable strategy for successful application development and timely deployment in several research studies, such as [16]. The rapid prototyping approach suggested by Billinghurst and Nebeling [17] improved the prototyping processes for creating the AR product. The iterative approach in RAD is beneficial for developers to address changing customer needs by allowing changes to be implemented as the project advances. User engagement contributes to the development of a better-tailored application that meets their expectations. Utilizing reusable code from open-source platforms streamlines the development process. Thus, we adhered to all the phases in the RAD system development process.

The phases consist of the system requirements planning phase (phase 1), the user design phase (phase 2), the construction phase (phase 3), and the cut-over phase (phase 4). Figure 1 displays the phases. RAD focuses on creating a prototype that offers quick responses throughout the development and testing phases. RAD techniques were primarily implemented to expedite the application development timeline, ensuring superior system functionalities and feature outcomes. The details of each step completed are explained based on the model depicted in Figure 1.

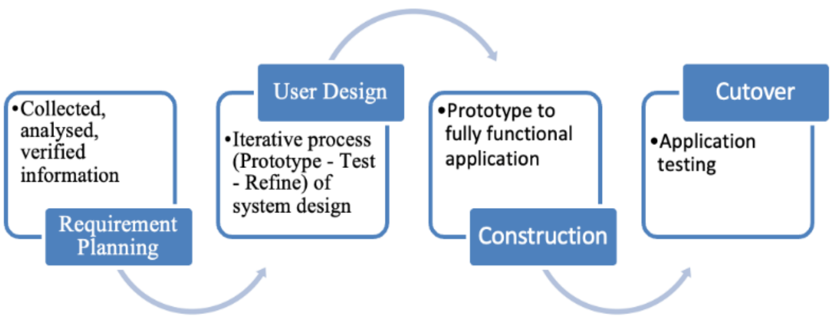


Figure 1. RAD methodology step-by-step processes

- Phase 1: the application was built in conjunction with Malaysia's national day, and all learning materials correspond to the national day theme. The researcher collected all information concerning the national day, analyzed the necessary WebAR applications, and verified the information with the users once again.
- Phase 2: this phase is concerned with the iterative process of system design. The process begins with storyboarding, proceeds to prototype, then involves testing with a consistent group of users (the same users as phase 1), and concludes with refining the system based on input gathered from the users. System design includes making a 3D model and then creating 3D animations. The approved design is subsequently submitted for construction.
- Phase 3: the results from phase 2 were combined, and the prototype was developed into a fully functional WebAR application. All 3D models, markers, and overlay AR elements are placed together during this phase.

- Phase 4: system evaluation is performed at this juncture to finalize the WebAR application. All components undergo comprehensive testing to verify their proper functionality. After we completed the application testing, we conducted usability testing with random users. This study assessed the usability of marker-based 3D WebAR application displays and their functionality with the user experience questionnaire (UEQ) [14]. The aim was to investigate how the display of 3D object projection on user's mobile screens affects the user experience of marker-based AR applications. The developed 3D WebAR application was uploaded on the research group website (https://ccrghub.com/iris/ar-scene/index.html).

The next section will further explain the details of the evaluation study and the materials used in this study.

2.1.1. Experimental design, tools, and participants

The pre-and post-experimental design was chosen in the evaluation study. This approach was selected because it could help the study achieve its goal by obtaining participant input regarding the usefulness of using marker-based augmented reality to improve their experiences. Questionnaires were used as the tool in this study to collect data before (pre) and after (post) the experiment was conducted. The pre-experiment questionnaire is intended to collect information about participants' background, level of knowledge, and participant's impressions of augmented reality. The participants were given the questions before they began using the 3D WebAR app. Considering that some of the participants were unfamiliar with the technology, the researcher offered some explanations. The post-experiment session was designed to collect participants' feedback on the usability criteria of the marker-based AR application.

The UEQ was used for that specific purpose. UEQ can efficiently gauge user experiences of a product [18], and it has been shown to be a reliable technique for measuring user experience based on previous research [19], [20]. The post-experiment questionnaire is administered to the participant upon completion of their interaction with the 3D WebAR application at the end of the testing session. Usually, the participant takes at most five minutes to complete the questionnaire. The UEQ employs pairs of contrasting attributes categorized into six components: attractiveness, efficiency, perspicuity, dependability, stimulation, and novelty. Each of these components is explained below;

- Attractiveness refers to the user's perception of a product based on features such as unpleasant or delightful, good or awful, unlikeable, pleasant, appealing, and friendly.
- Efficiency is determined by the user's perception of how effectively they are utilizing the product. The attributes used to assess efficiency are speed, efficiency, practicality, and organization.
- Perspicuity refers to the ease of comprehending how to use the product. These components are identified by attributes such as comprehensibility, ease of learning, complexity, clarity, and confusion.
- Dependability refers to the user's sense of control during product interactions. This sensation is evaluated based on characteristics that can be anticipated, hindering or aiding, providing security, and whether the item fulfills expectations.
- Stimulation refers to users' feedback indicating their excitement and motivation when using the product. This component is assessed based on feelings of inferiority, excitement, curiosity, and motivation.
- Novelty corresponds to the product design's innovation. This component is assessed based on creativity, inventiveness, cutting-edge ideas, and innovation.

The attributes for each component describe variations between contrasting elements. For example, pleasant or unpleasant, fast or slow, and complicated or easy. The rating scales utilize a seven-point semantic variance format. Participants can provide feedback on the product by marking the point that best represents their perception. When reflecting on favorable attributes, choices should align with those attributes; when reflecting on unfavorable attributes, choices should likewise align with those attributes. If the selection is in the middle, it signifies that it does not belong to either of the two attributes. Participants were directed to spontaneously express their impressions of the AR application when making decisions. At times, individuals may initially perceive attributes as unrelated, but as they advance through the questions, they will discover their interconnectedness.

The study engaged thirty individuals to participate in the usability testing. Based on the UEQ study in [21], a minimum of twenty participants shall be selected to accurately identify a significant number of concerns when using the questionnaire. The participants were randomly approached during the National Day exhibition. The exhibition took place at a commercial center in Kota Kinabalu, Sabah. The exhibition took place over two days on August 25 and 26, 2023. Every participant was informed that their participation was optional. If they do not choose to continue, they may refuse. The participants came from diverse backgrounds, including students, workers, parents, and local and international visitors, with ages ranging from 18 to 40.

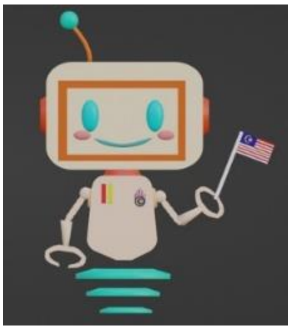
The experiment was intended to be conducted by the researcher and participant in an individual setting. Before the trial commences, the researcher will request that participants complete the pre-experiment questionnaire. Once the form is filled out, the researcher will instruct the participant on how to access the WebAR application and demonstrate how the AR functions, utilizing either the participant's personal mobile phone or the one provided for the study. Subsequently, the researcher will allow the participant to independently navigate the web. This time typically lasted between 5 and 10 minutes. After the participants are finished, they are required to fill out the post-experiment questionnaire.

2.2. The 3D WebAR model and application

Sixteen 3D models have been created for the WebAR application. The models were designed in Adobe Illustrator and then animated in Blender. The designs were based on the concept of Malaysia's national day, incorporating the national day emblem, national principles, Madani values, and an avatar. Out of the sixteen 3D AR models, Figure 2 displays four different examples used in this study. Figure 2(a) depicts a 3D AR model of a robot. Figure 2(b) displays one of the 3D AR models that animate Malaysia's MADANI logo. Figure 2(c) shows a 3D AR model of a hibiscus, which symbolizes the principles of the nation and animates based on its petals. Figure 2(d) represents a 3D AR model of a previous National Day logo.

WebAR architecture is utilized to enable the implementation of AR on the web. AR.js and three.js are key library files utilized in developing a WebAR application inside this framework. The libraries will allow for the display of dynamic 3D models using WebGL in a web browser. An AR marker is created for every model. Every marker is created using the MindAR compiler. The created marker is stored in a file with a *.mind extension. Figure 3 displays the example of marker points found by the compiler before saving them into the mind file. The compiler is a web-based AR library that utilizes JavaScript code combined with the three.js framework. This JavaScript code is open source and can be reused in any WebAR application.

Users can visualize the overlay AR using any mobile device without the need to install additional software or applications. Since the architecture is relatively new and continually evolving in terms of implementation, some libraries may not function on specific mobile devices. As such, the AR visualization may not work properly when using a mobile device that has the most recent operating system update. The WebAR application can be found on the project website. The image displays markers on top of each button, which may also be found within the printed book for easy scanning. Figure 4 exhibit the user interfaces of a 3D WebAR application. Figure 4(a) shows the user interfaces that appear when the mobile device's camera is activated after clicking the page number button. Users should direct their cellphone camera towards the marking. Figure 4(b) displays the interface of the 3D object when the marker is detected.



(a)

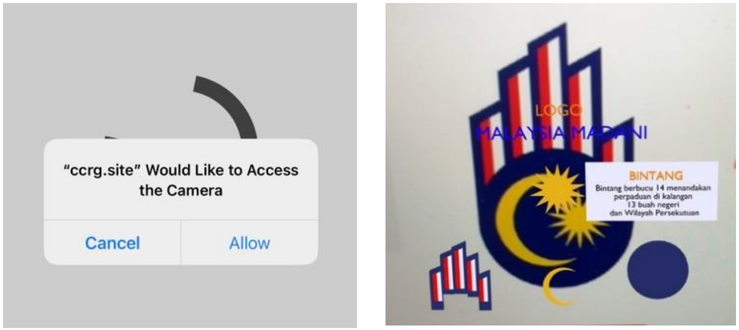
(b)

(c)

(d)

Figure 2. Example of the 3D AR models extracted: (a) robot avatar, (b) Malaysia MADANI logo, (c) national's principles, and (d) national day old logo

Figure 3. Example of marker generation using MindAR.js



(a) (b)

Figure 4. The 3D WebAR application (a) when camera access is requested and (b) the projected 3D object when the camera is pointed at the marker

3. RESULTS AND DISCUSSION

Thirty participants were involved in the study. Table 1 shows the distribution of participants's demographics. The age range varies from 10 to 50 years old. However, the majority of them are aged between 30 and 49 (N = 19). The experiment was conducted equally by females and males. Figure 5 displays the distribution of participants by age and gender. Of the participants, around 57% (N = 17) were at an intermediate level of technology-savvy users, 33% (N = 10) were at an advanced level, and 10% (N = 3) were at an expert level. None of them were novices.

Twenty-six items were asked in UEQ, and these items were grouped under six components: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The Cronbach's alphas for these components are shown in Table 2. The attractiveness component consisted of 5 items (a =.83), the perspicuity component consisted of 4 items (a =.63), the efficiency component consisted of 4 items (a =.78), the dependability component consisted of 4 items (a =.71), the stimulation component consisted of 4 items (a =.78), and the novelty component consisted of 4 items (a =.71). According to the UEQ score's interpretation in [21], all components were found to have an α value ranging from .6 to .8, indicating acceptable consistency.

Table 1. Participant demographic

	Demographic	No	Percentage
Gender	Female	15	50%
	Male	15	50%
Age	10 - 19	5	17%
	20 - 29	5	17%
	30 - 39	8	27%
	40 - 49	11	37%
	50 and above	1	2%
Technology savvy user	Basic	0	0%
	Intermediate	17	57%
	Advanced	11	33%
	Expert	3	10%
AR experience	Yes	3	10%
	No	27	90%
Level of education	Secondary school	7	23%
	Tertiary	23	77%

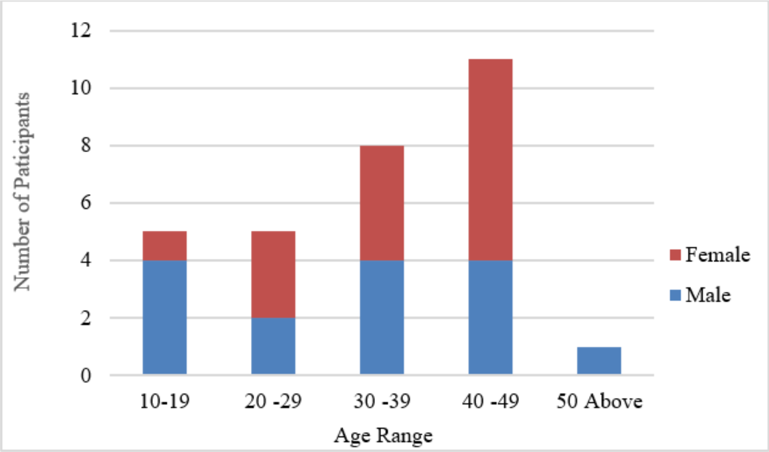


Figure 5. Participant age vs gender

Table 3 displays the mean, standard deviation, and confidence for all components. The UEQ standard interpretation for standard deviation [18] indicates that users exhibit medium agreement across five components: attractiveness, perspicuity, dependability, stimulation, and novelty. Users have low consensus on component efficiency.

Table 2. The component's Cronbach's alphas

Component	No. of iItems	Cronbach's alphas (α)
Attractiveness	5	.83
Perspicuity	4	.63
Efficiency	4	.78
Dependability	4	.71
Stimulation	4	.78
Novelty	4	.71

Table 3. The mean, Std. Dev, variance, and confidence

Confidence intervals (p=0.05) per scale							
Scale	Mean	Std. Dev.	Var	N	Confidence	Confidence interval	
Attractiveness	2.217	0.921	0.85	30	0.330	1.887	2.546
Perspicuity	2.175	0.915	0.84	30	0.327	1.848	2.502
Efficiency	1.983	1.093	1.19	30	0.391	1.592	2.374
Dependability	1.958	0.947	0.90	30	0.339	1.619	2.297
Stimulation	2.075	0.992	0.98	30	0.355	1.720	2.430
Novelty	2.208	0.910	0.83	30	0.326	1.883	2.534

The mean and variance values of each component in Table 3 determine if the product meets the expected user experience standards. Figure 6 displays the graph distribution. According to UEQ standard interpretation, variance scores ranging from -.8 to .8 signify a neutral evaluation of the dimension, scores exceeding .8 suggest a positive evaluation, and scores below -.8 imply a negative evaluation. The average rating must fall between the -3 (very poor) range to +3 (excellent) for the observation. The results indicate that the mean falls within the specified range. Thus, the 3D WebAR application was well-received in terms of user experience.

The UEQ provides benchmarking of our product among 468 product assessments that are updated annually utilizing the UEQ analytical tool. The analysis results demonstrate that the 3D WebAR application received an excellent user experience rating, ranking among the top 10% of results, as depicted in Figure 7. The UEQ scales can be categorized into pragmatic quality (perspicuity, efficiency, and dependability) and hedonic quality (stimulation, originality). Pragmatic quality pertains to quality elements connected to tasks, while hedonic quality refers to quality features not related to tasks. The mean of the three pragmatic and hedonic quality elements can be found in Figure 8.

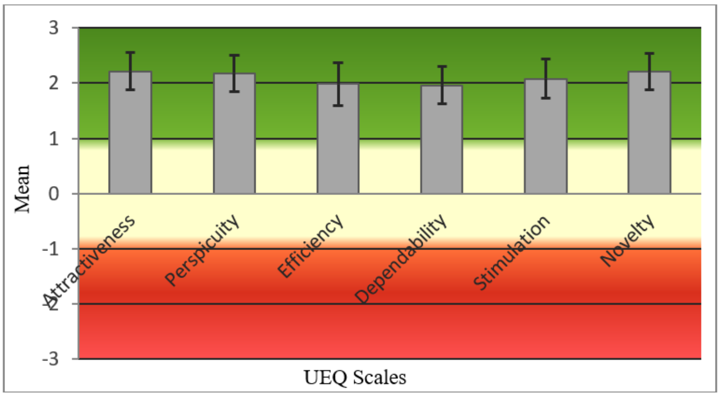


Figure 6. The UEQ graph distribution by item

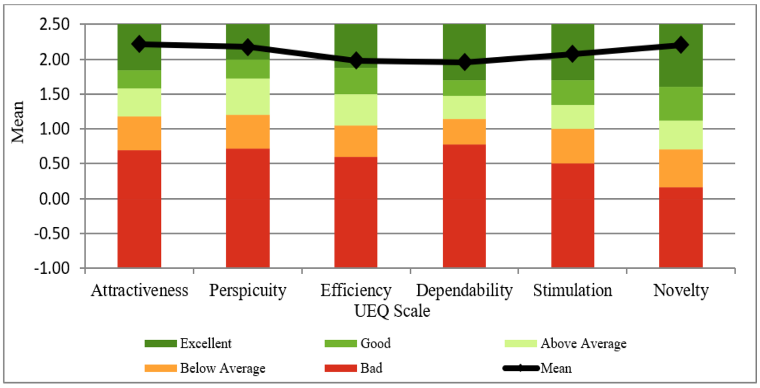


Figure 7. The user experience rating

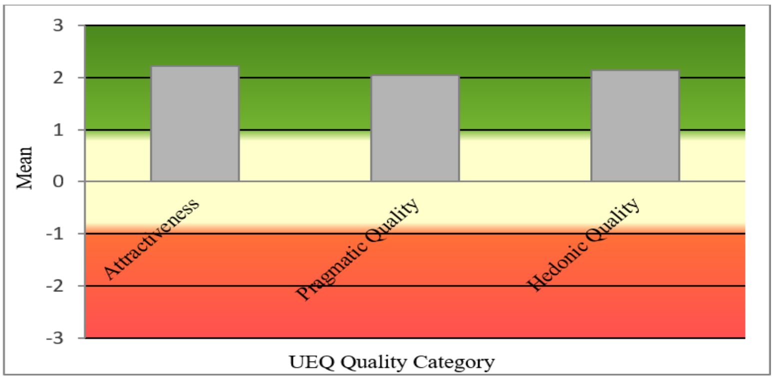


Figure 8. The mean of attractiveness, pragmatic, and hedonic

The results in Figure 8 indicate that the WebAR application has a user-friendly design that focuses more on hedonic attributes such as stimulation and novelty, rather than pragmatic criteria like efficiency, perspicuity, and dependability. Hedonic variables prioritize user enjoyment over practical usefulness, while pragmatic qualities focus on the product's effectiveness and functionality. Based on our findings, WebAR platform developers should acknowledge the substantial influence of user experience on the success and efficacy of their products. Our result suggests that the WebAR application also has a similar implication of user experience to mobile AR applications in [19], [22], whereby the dynamic visualization supports the user in understanding the context of the application. Therefore, WebAR programs should prioritize clarity and usability to boost user happiness, enabling users to accomplish their goals with minimal effort. A similar suggestion was also proposed by [23] in enhancing user experience, particularly before the application is fully implemented. Clear and concise instructions should be provided at the beginning of the application due to the newness of WebAR technology and potential unfamiliarity among users. Moreover, interactive elements should be used to promote user participation [24].

Nevertheless, this study has certain limitations that were identified for future investigation. The assessment is conducted only once, utilizing the UEQ during the real-time event of the national day exhibition. The collected data could be further enriched by using additional user experience testing methods like thinking aloud or heuristics. Furthermore, we observed that marker-based WebAR has its own limitations. The constraint is in the marker's reliability, the capabilities of mobile phones and tablets, and the strength of the internet connection. Nevertheless, these limitations do not significantly impede users' experiences when interacting with the 3D items.

4. CONCLUSION

This study has provided valuable insights into the user experiences of marker-based 3D WebAR applications, using the UEQ as an evaluation tool. Users discover marker-based 3D WebAR applications positively in terms of usability, aesthetics, stimulation, and efficiency, according to the data. Specific areas for improvement include improving marker identification accuracy, mobile platform capabilities, and refining user interfaces for a better user experience. The examination of user input and interaction patterns has emphasized the significance of user-centered design concepts in creating marker-based 3D WebAR experiences. By integrating user feedback into the iterative design process, developers can craft more intuitive, appealing, and immersive experiences that address users' varied needs and preferences. This research adds to the expanding knowledge base on web-based augmented reality and offers practical guidance for designers and developers aiming to improve the usability and user experience of marker-based 3D WebAR applications. Future research may explore different evaluation approaches, study the extended user engagement with marker-based 3D WebAR experiences over time, and analyze how evolving technologies affect the development of web-based augmented reality.

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