Enhancing User Experience in Mobile-based Augmented Reality during Dynamic Content Delivery

A Thesis Submitted for the Degree of Master of Computer Science

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DECLARATION

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ABSTRACT

Augmented Reality (AR) is defined as the technology and methods that combine real-world objects and computer-generated content. With the proliferation of mobile devices, Mobile Augmented Reality (MAR) has emerged as the most popular and most convenient form of augmented reality. MAR applications can be implemented in two ways. Conventionally and dynamically. In a dynamic nature, content is loaded from an external server. However, the major problem with loading data from external servers/clouds is that it takes time to load content. In MAR applications, users must continuously position the camera towards the target until content is loaded to the screen. But, due to the delay in loading the target, users may not continuously position the camera toward the target and don't keep their attention towards the target, until processing the content. Hence, methods need to be introduced to keep the attention of the users. This research considered the methods to enhance the user experience while content is being loaded onto the mobile screen.

First, a prototype is developed without any enhancements with three types of content (Text, Image, and Video) needed to be loaded onto the screen using Unity Vuforia and Firebase technologies. With the questionnaire using 20 participants, it is identified that, with the content becoming greater, there is a need to improve the user experience while content is being loaded. Then, with the help of a literature survey, five prototypes were developed using different types of enhancements with the target being to improve the user experience while video content is being loaded. Then, another questionnaire was performed with the same 20 participants to compare these five prototypes with the previous prototype with no enhancements. According to the results from the calculations, it can be concluded that the usage of enhancements has a positive impact on user experience.

Hence, it can be concluded that there is a significant importance in improving the user experience when content is loaded in a dynamic nature.

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ABBREVIATIONS

AR	Augmented Reality
MAR	Mobile Augmented Reality
UX	User Experience
CMR	Cloud Mobile Rendering
PF	Pure Front-End
PE	Pure MEC
PC	Pure Public Cloud
QoE	Quality of Experience
ILF	Initial Loading Feedback

CHAPTER 1

INTRODUCTION

1.1 Motivation

With evolving technology, the data obtained about our environment is richer than ever before. It also seems that it is giving more choices but less time to think. To keep up, need something that would help us to comprehend information and make decisions faster. One way to close the gap between the digital and the physical world is “Augmented Reality” technology.

Augmented Reality (AR) is defined as the technology and methods that combine real-world objects and computer-generated content such as videos, infographics, 2D/3D images, sounds, etc. using an AR device and creating intended meanings.

AR is used to scan real-life surroundings, simultaneously analyze the scanned target, and show users virtual content related to the real world in front of the camera. Looking at the screen, the user sees the real object and the information presented by AR software simultaneously (AZUMA et al., n.d.).

During the past few years, AR has become one of the biggest technology trends in the world and there have been many augmented reality applications used in different industries/fields in the world such as Gaming, Retail and Advertisement, Logistics, Manufacturing, and Maintenance, Education, Military, Tourism, Medicine/Healthcare (VAN KREVELEN and POELMAN, n.d.).

Due to the proliferation of mobile devices, Mobile Augmented Reality (MAR) has emerged as the most popular and most convenient form of augmented reality. Mobile AR takes advantage of the widely distributed base of hardware such as smartphones and tablets.

Figure 1 shows an example of how a Mobile Augmented Reality Application works.

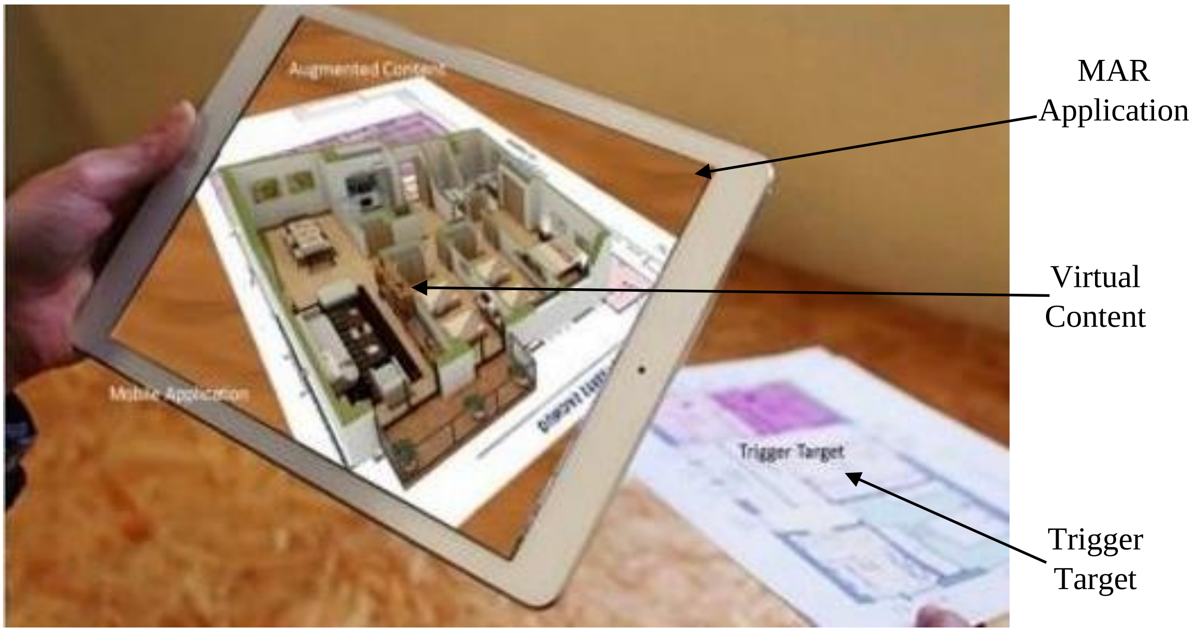


Figure 1: MAR Application

1.2 Statement of the problem

Consider a scenario in a supermarket, where a marker-based MAR system can be adopted as shown in Figure 2. In marker-based MAR (KATO and BILLINGHURST, n.d.), an AR camera usually recognizes an object/target/marker and starts tracking it, then shows virtual content (2D/3D images, texts, videos, content blocks, or animation) related to the marker. Using this, the MAR system can be enabled to show content like discounts, best-sale products, promotions, credit card offers, and many other characteristics when a person targets the camera of a mobile device.

Figure 2: Example of a Marker-based MAR application

MAR applications can be implemented in two ways conventional and dynamic nature. Conventionally, targets/contents are already embedded in the device's local storage and do not support content changes/updates dynamically. In a dynamic nature, targets/contents are stored in an external server (cloud computing), and possible to change the targets/contents dynamically for product or business owners. Mobile devices are only designed for common functionalities such as telephone and Internet access. Therefore, there are some limitations, (SIRIWARDHANA et al., 2019) in conventional methods such as limited storage, battery life, and processing power. Hence content loading in a dynamic nature is most popular and prominent due to limitations in conventional methods and dynamic content loading facilities (QIN et al., 2021a).

Large communication delays could be introduced by offloading computing tasks to the cloud and loading contents of a dynamic nature due to bandwidth and latency challenges (limited data rate and unacceptable network delay). Due to the delay, users may not continuously position the camera toward the target and don't keep their attention towards the target, until processing the content. But, when the camera is not focused on a particular spot, the virtual content may not load properly. Hence, it is important to keep the user's attention to position the AR camera on top of the target, otherwise, these factors have badly affected the user's experience (UX) of MAR applications in a dynamic nature (EGGER et al., n.d.).

1.3 Research Aims and Objectives

1.3.1 Aim

Marker-based MAR products are required to keep user interaction until the device identifies the target and loads relevant content. The main Aim of this research project is to analyze and verify the issues and problems that affect the user experience (UX) of augmented reality applications (AR) on mobile devices when loading content in dynamic nature.

1.3.2 Objectives

MAR applications can load targets and contents from either the device's local storage or external servers. Loading data from an external server is mostly popular due to dynamic content change facilities, avoiding storage, battery life, and processing power limitations of mobile device storage. However, the major problem with loading data from external servers/clouds is that it takes time to load content. Hence, AR-based products are required to keep user interaction until the device identifies the target and loads relevant content. The main objective of this research project can be categorized as below.

- Review and study work of literature regarding the matter and based on that, identify the approaches to enhance the user experience when content loads dynamically and keep user interaction while Mobile Apps load the content.
- Create a mobile application as the prototype consisting of the content management system.
- Using a questionnaire, identify uses and concerns according to the user experience when content loading dynamically.
- Based on the results of the above questionnaire and literature, improve the prototype using enhancements and capture the user experience again.
- Evaluate the user experience of the application with an unbiased real-user evaluation plan.

1.4 Scope

The scope of the proposed research is limited to Marker Augmented Reality Mobile applications of a dynamic nature.

- Study current MAR trends available and review the literature regarding the matter.
- Analyze currently available MAR applications and compare used technologies, performance, and data storage methods and compare their user experience between them.
- The study selected technologies and developed a MAR prototype application to analyze user experience when content loading dynamically using a questionnaire.
- Identify solutions and enhancements to the research problem and evaluate proposed solutions with different test objectives.
- Summarize the results of the research.

CHAPTER 2

LITERATURE REVIEW

Due to the proliferation of mobile devices, Mobile Augmented Reality (MAR) has emerged as the most popular and most convenient form of augmented reality. MAR Applications can use two types of storage appliances for their useability. They are,

- Mobile device's internal storage
- External server (example: Cloud)

When considering the usage of internal storage of the mobile device as MAR Application's storage, there can be many complications. The user always expects high-quality results from the application and the quality of the graphics is a huge factor contributing to the user experience and it creates interactive communication between end users. Also, limited content reduces user experience. The quality of the content means that the content is large and needs to move the content to external servers due to the limited storage in the mobile device's internal storage (DAVIDAVIČIENĖ, 2020).

MAR is involved in rich multimedia applications like 3-D graphic rendering, and it is not only very computationally intensive; it can also impose severe challenges on the limited battery capability of an always-on mobile device. Cloud mobile rendering (CMR) is an alternative approach, where compute-intensive rendering is performed on cloud servers instead of on mobile devices, and the rendered video is encoded and streamed to mobile devices(LIU et al., 2014).

When consumers can control the content, presentation, computer-generated imagery objects, or the environment proffered by the MAR app, they likely will perceive it as both easy to use and useful, which are vital constructs in both the technology acceptance model and Success models (QIN et al., 2021b). The Most suitable way to control content is to keep content out of the device storage, within an external server (dynamic nature).

MAR applications are power-hungry, as they need so much energy to give the user a proper experience. The need for the sensors to cooperate over a long period, the analysis of the information, computing, communication, and display, puts tremendous pressure on the battery of the mobile device are the many things that required by the MAR applications and that puts tremendous pressure on the battery of the mobile device. The extreme energy consumption referred to will significantly hinder the deployment of Web AR on common mobile devices. The computation outsourcing mechanism can alleviate the energy consumption of the end device by offloading computing pressure to the cloud (XIUQUAN QIAO et al., 2019).

Also, MAR applications that involve 3-D graphic rendering are not only very computationally intensive; they can also impose severe challenges on the limited battery capability of an always-on mobile device. Cloud mobile rendering (CMR) is an alternative approach, where compute-intensive rendering is performed on cloud servers instead of on mobile devices, and the rendered video is encoded and streamed to the mobile devices. The CMR approach has several advantages (LIU et al., 2014).

- High scalability across various mobile platforms.
- Able to use the most advanced rendering technologies, without concern about computation constraints, and hence be able to provide the richest graphic rendering quality.
- CMR-based applications will have significantly less battery consumption than if rendering is performed on the mobile device itself, thus making such rendering applications feasible and popular on mobile devices.

Table 1 shows a comparison of different Architectural options for MAR applications and shows a good idea of how Cloud-based applications are better than Local Storage MAR applications (SIRIWARDHANA et al., 2019).

Table 1: Comparison of Different Architectural Options for MAR

Item	Cloud-Based	Localized
Nature of Applications	Suitable for centralized applications used by a vast number of distributed users.	Server-based architecture is suitable for highly specialized and isolated applications, with multiple devices. Local on-device architecture is suitable for isolated applications with strict security
AR Server Location	Cloud	Local network or on-device
Latency	< 50 ms Communication latency is higher than other architectures due to the cloud AR server deployment.	20 ms for server-based and < 5 ms for local on-device Applications require ultra-low latency. having the key requirement of keeping the data locally.

Item	Cloud-Based	Localized
MAR device Energy Consumption (Noreikis et al., n.d.)	Low Due to computational offloading	Low for server-based setup and very high for on-device setup Based on the level of processing at the device
Scalability in terms of supported MAR devices	Cloud-based MAR Applications support a higher number of devices.	Depends on the resources of the local server

Hence, these studies show that Cloud-based MAR applications are better than the Localized MAR applications due to

- Storage and computational power limitation
- Facility to dynamic content.

But, Cloud-based MARs also have limitations. One such thing that could occur is communication problems. Large communication delays can occur when offloading computing tasks to the cloud. It is therefore difficult for current mobile networks to support real-time operations (e.g., tracking and interaction), due to the limited data rate and unacceptable network delay. However, the following issues cannot be ignored.

- Bandwidth Challenge: The continuous image/video transmission occupies a large part of the network bandwidth, which has a bad impact on core networks.
- Latency Challenge: An additional communication delay is added due to the data transmission, and an unstable wireless environment also aggravates the performance of Web AR applications (SIRIWARDHANA et al., 2019).

Figure 3 shows the comparison of Mobile AR over Frames per second, latency, and power consumption according to PF (Pure front-end), PE (Pure MEC), and PC (Pure Public Cloud). Figure 3 shows that large latency cannot meet high interactive demands, and this will lead to poor user experience. the average latency can be as large as 51 ms and 130 ms and will be much worse over a deteriorated wireless channel that suffers from interference, congestion, signal fading, etc (Xiuquan QIAO et al., 2019).

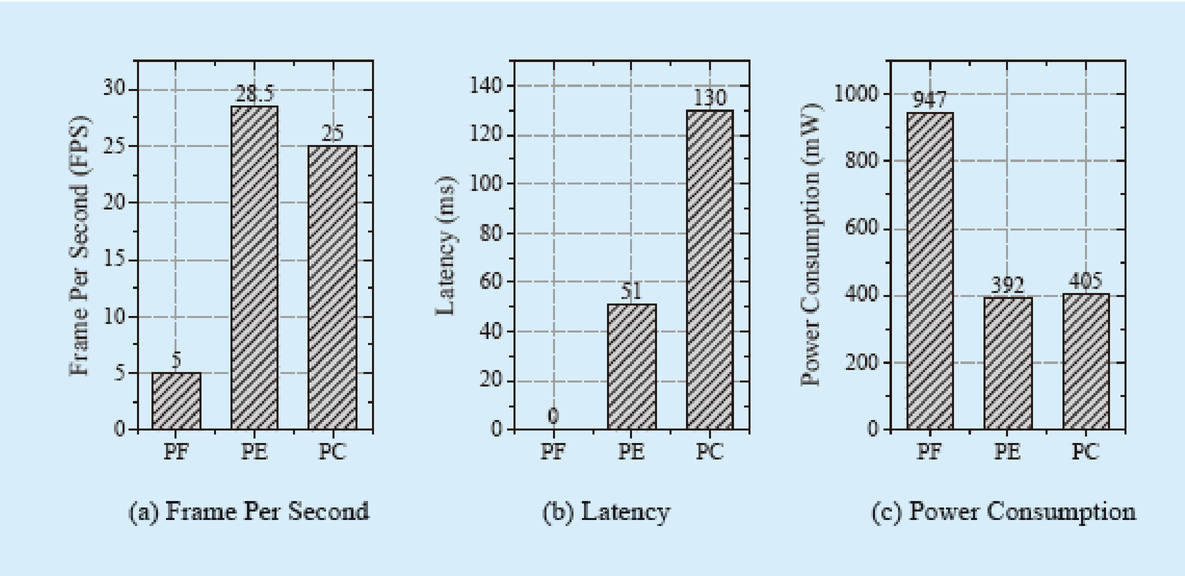


Figure 3: The Performance of Mobile Web AR over 3G/4G networks in terms of FPS, latency, and power consumption (PF-Pure front-end, PE Pure MEC, PC: Pure Public Cloud)

Table 2 shows some research done to check how the user experience behaves with the response time. Response time negatively affects users' tolerance, acceptance, and satisfaction differently, such that this negative effect is strongest for satisfaction, followed by acceptance, and then tolerance (YU et al., 2020).

Table 2: Relationship between response time and user experience

Year and authors	Antecedents	Area	Dependent variables	Response time conditions	Major findings
Hoxmeier and DiCesare (2000)	RT (Response Time)	Computer system 100 students	Ease of use and ease of learning, satisfaction, system power, and reuse	0,3,6,9,12 s	Satisfaction decreased when response time increased, the level of intolerance occurred in the 12 s response range
Otto et al. (2000)	Download Time	Web pages 60 students	Elements of user's satisfaction content, format, ease of use, appeal of graphics and responsiveness)	0,15 s	15 s or less delays did not impact users' overall satisfaction
Galletta et al. (2004)	RT	Web pages 196 students	Attitudes (satisfaction with the site), Behavioral intentions (return to a site)	0,2,4,6,8,10,12 s	When delays were over 4 s, performance and behavioral intentions

Year and authors	Antecedents	Area	Dependent variables	Response time conditions	Major findings
					decreased; when delays were over 8 s, the attitudes became flattened.
Nah (2004)	Feedback during the wait	Web pages 170 students	Tolerable waiting time	Infinite waiting time, Negligible download time	Feedback can prolong user's tolerable waiting time
Hong et al. (2013)	Wait time. Amount of information. Direction of attention	Web pages for business 72 females and 135 males (study 1); 58 females and 81 males (study 2)	Perceived quickness of the wait; Negative affective toward the wait	Short wait: 10 s. Long wait: 45 s	The shorter waits with additional visual content may make. users' waiting feeling longer

The above research performed an analysis to identify the trend of user experience concurrently with the increase in response time. As shown in Figure 4, the mean value of the user's experience—reflected by tolerance, acceptance, and satisfaction—decreased when response time increased.

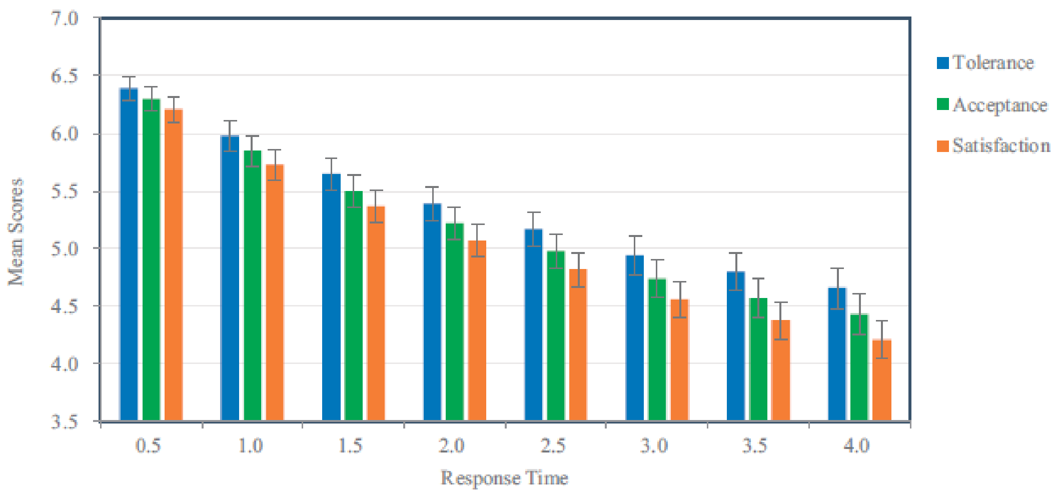


Figure 4: Comparison of Tolerance, Acceptance, and Satisfaction vs Response Time

The user experience of CMR (Cloud mobile rendering) applications can be determined by following three subjective factors: graphic quality, video quality, and response time. Figure 5 shows a few of the objective and subjective factors affecting the user experience of CMR applications (LIU et al., 2014).

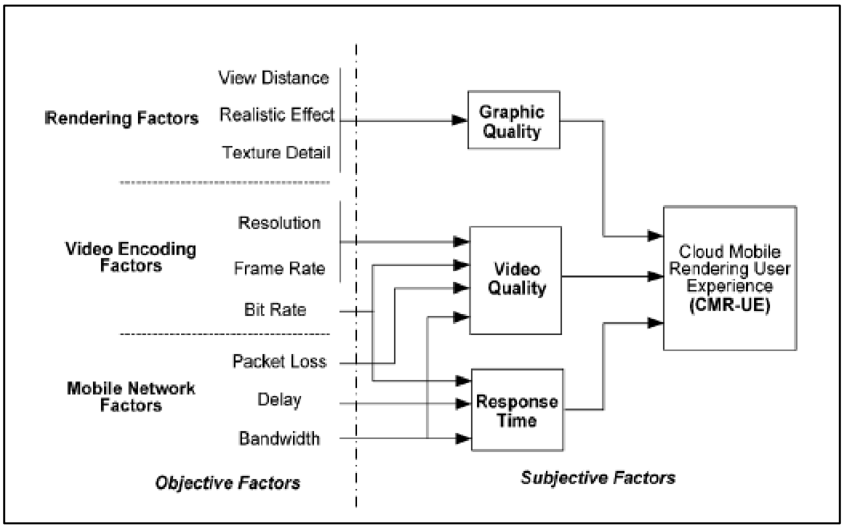


Figure 5: Objective and Subjective factors affecting user experience of CMR applications

When talking about improving the latency of MAR applications, comparing the latency in terms of 5G, Wi-Fi, and LTE networks is another important subject. The following is a result of research that compared the latency between the above-mentioned networks (Mazri Yaakob, 2019).

Figure 6 depicts the latency system results that show a 5G edge-enhanced connection to minimize the time taken for transferring data by 25% when compared to LTE and 55 percent for Wi-Fi. But still, 5G shows latency in MAR applications and this is proof that when the content is being loaded from the external servers. Although, several technological advances have started to enter the landscape of MAR.

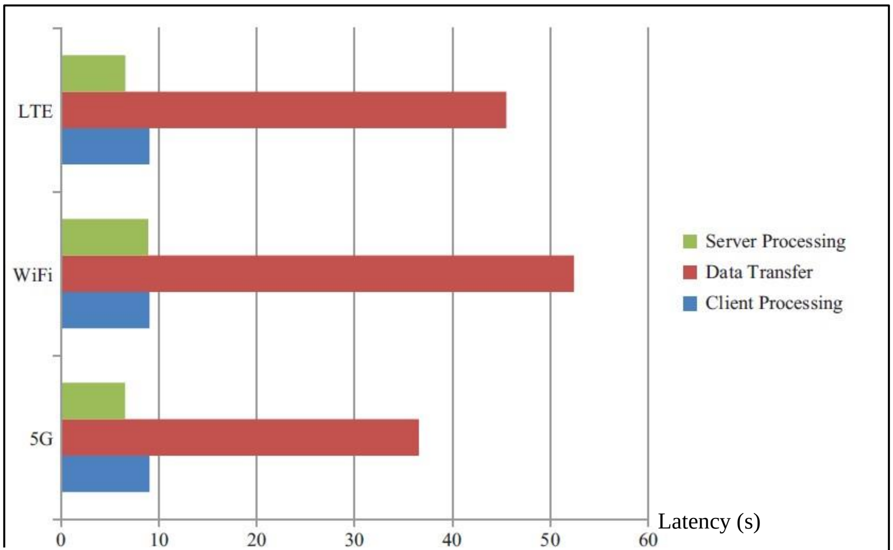


Figure 6: Latency of the proposed MAR system

The upcoming 5G networks (ANDREWS, 2017) bring new opportunities for MAR, especially Web AR. They provide higher bandwidth (0.1~1 Gb/s) and lower network delay (1~10 ms), which improves the data transmission on mobile networks.

When users face loading time, they tend to get frustrated and even close the page. Hence, Researchers have paid much attention to web users' tolerable waiting time, and have worked on how to design loading symbols and interfaces to improve users' quality of experience (QoE) (WANG et al., 2021).

Figure 7 shows the 4 common types of Initial loading Feedback (ILF) (i)Null, (ii)Circle, (iii)Logo, and (iv)Combination were used for the comparison according to the following indicators. (dependent variables)

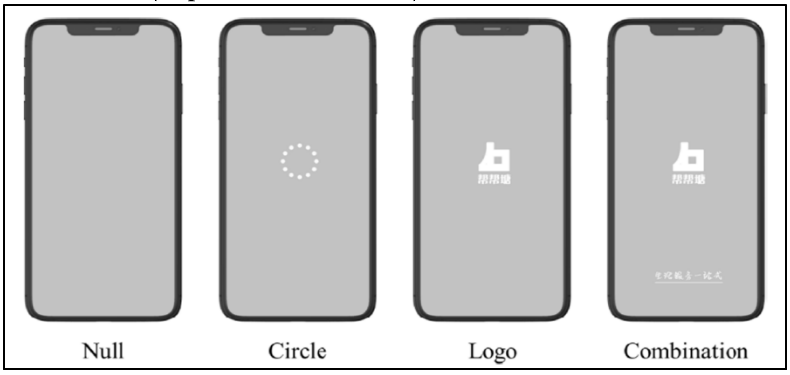


Figure 7: Four types of initial loading pages

Single factorial repetitive measurement was used in the experiment; users' responses to questions were collected. The independent variable was the formation of loading feedback and the dependent variables (Figure 8) included the waiting mental state and waiting behavior.

As shown in Figure 8, users' mental state was measured by using users' emotional experience, time perception, and preferences. The first two indicators were investigated using six questions (Table 2) on a seven-point Likert scale, whose values ranged from 1 to 7. The design of the emotional experience scale was based on the pleasure-arousal, dominance model. For the measurement of time perception, the research in this field, users' evaluations of attention, time distortion, and their perception of time interval (speed) were used. The six indicators expressed the following mental states respectively:

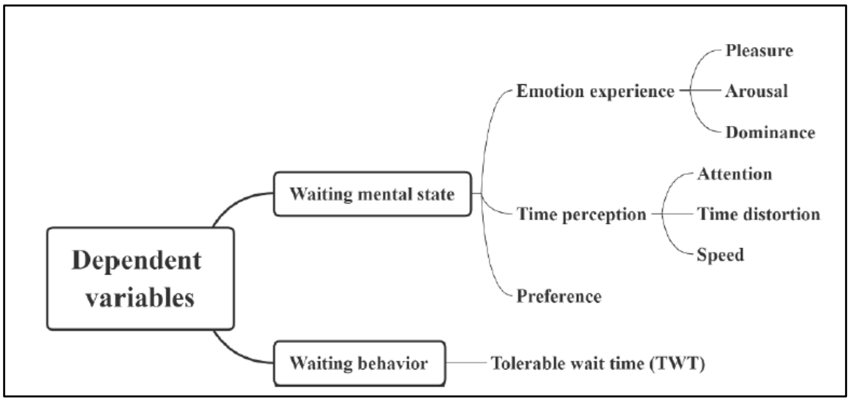


Figure 8: Dependent variables and indicators considered for the questionnaire

Table 3: Questionnaire used for the survey

Survey questions.

Indicator	Item	Question
Emotional experience	Pleasure	Sad 1 2 3 4 5 6 7 Happy
	Arousal	Calm 1 2 3 4 5 6 7 Excited
	Dominance	Passive 1 2 3 4 5 6 7 Active
Time perception	Attention	Distracted 1 2 3 4 5 6 7 Focused
	Time distortion	Tense 1 2 3 4 5 6 7 Neglect the passage of time
	Speed	Feel time passing slowly 1 2 3 4 5 6 7 Quickly

Results according to the above variables can be shown in Figure 9, Figure 10, Figure 11, and Figure 12.

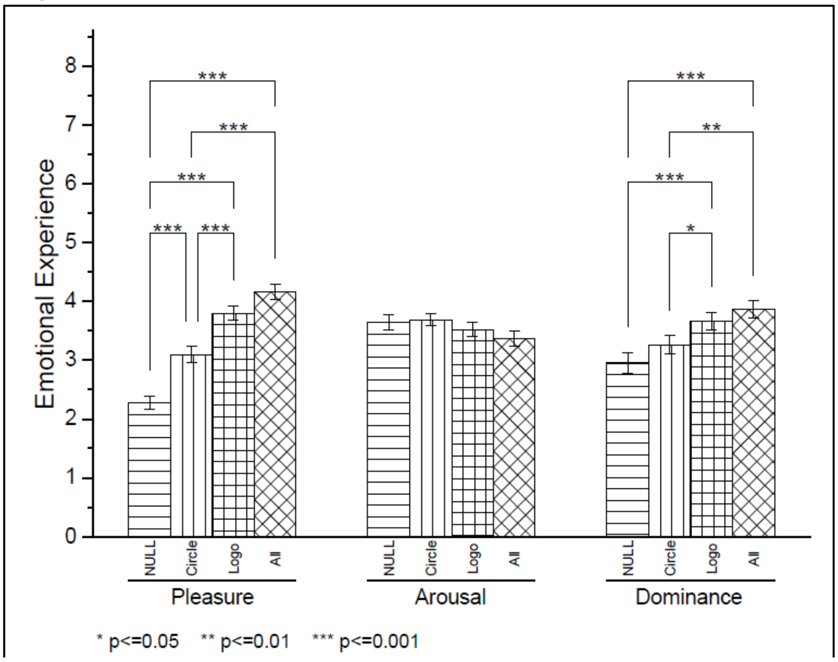


Figure 9: Comparison of different ILF methods in terms of Emotional Experience

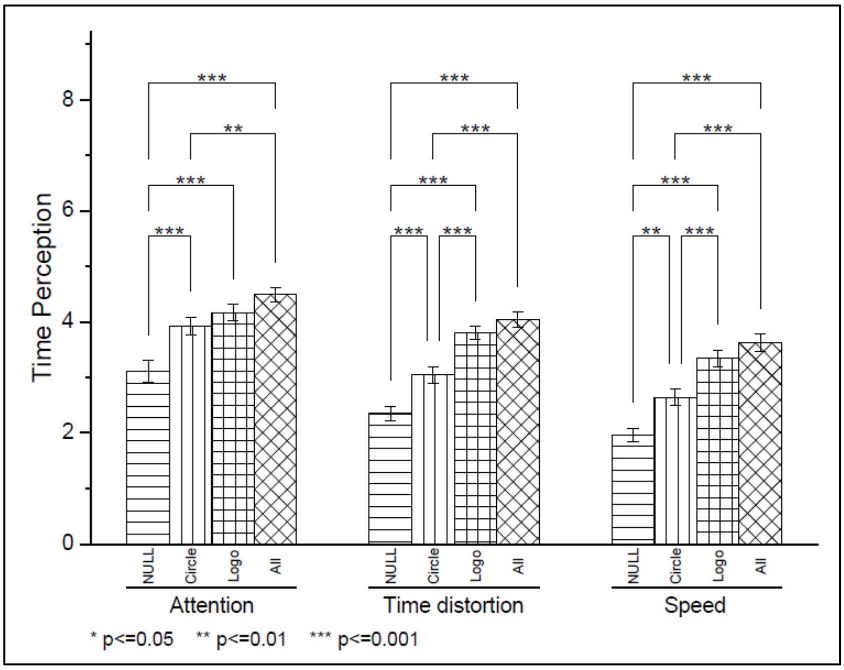


Figure 10: Comparison of different ILF methods in terms of Time Perception

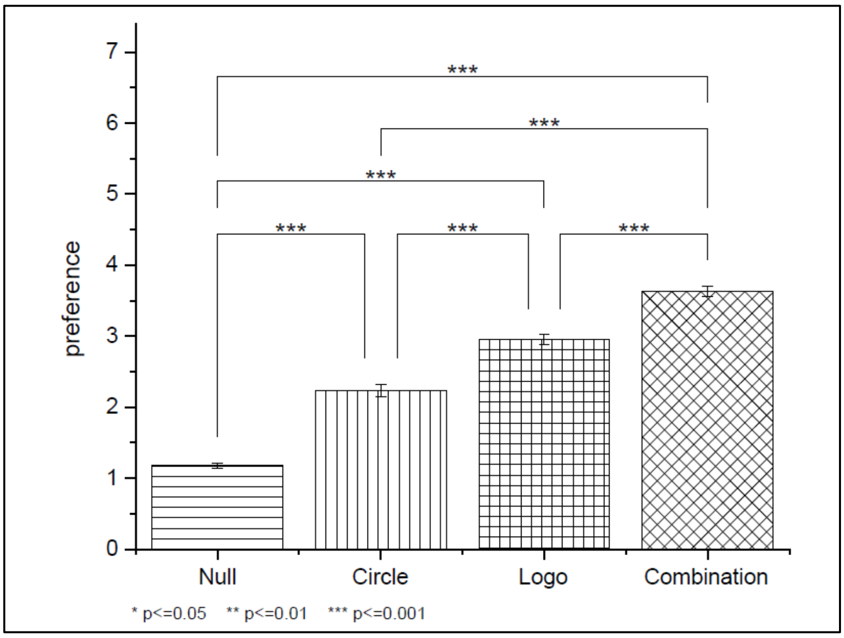


Figure 11: Comparison of different ILF methods in terms of Time Perception

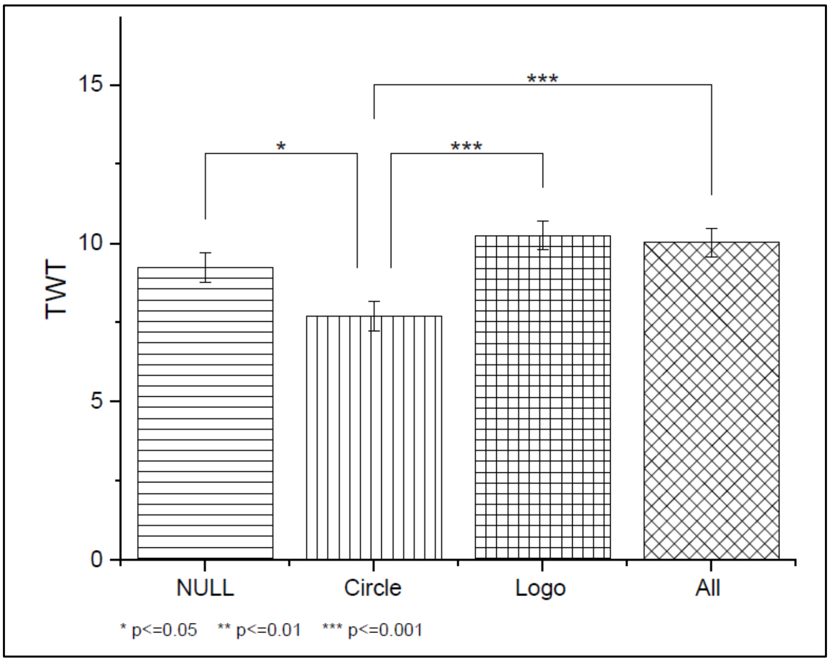


Figure 12: Comparison of different ILF methods in terms of Tolerance of wait time

The results showed that using the Combination, of a logo plus a slogan, as a loading indicator improved participants' waiting evaluation. However, there was generally no significant difference between using a simple logo and using the combination of a logo and a slogan as loading feedback. The following conclusions can be obtained from this.

- Different types of ILFs influence users' emotional experiences. Using a logo in the initial loading interface gave users a higher degree of pleasure and arousal than using a rotating circle. The combination of a logo with a slogan gave people a more pleasant wait than others, while a blank interface performed the worst.
- The types of ILFs influenced users' time perception. A loading screen logo caused users to exhibit high levels of attention, time distortion, and sense of speed compared to a rotating circle, which in turn outperformed the Null type.

Hence, there is a significant improvement to the MAR applications if suitable Initial loading feedback is considered.

An Experimental study was done to find out the importance of progress indicator design in mobile applications (Willermark et al., 2021) highlighting the fact that the "percent" progress indicator had higher user satisfaction. That study aims to gain increased knowledge of user satisfaction and subjectively experienced time in interaction with mobile applications. This research evaluated three mobile applications containing unique stimuli in progress indicators. Following Table 4 shows the used stimuli with different progress indicators. A questionnaire-based survey was performed to analyze the results. This shows that the “Percent” progress indicator was associated with the highest user satisfaction, followed by “Linear” and “Repetitive”.

Progress indicator	Degree of feedbac k (3 Levels)	Illustration of the progress indicator launching the application	Illustration of the progress indicator inside the application
Repetitive	Low		
Linear	Medium		
Percent	High		

Table 4: Experimental Stimuli of the different progress indicators

This study shows that the degree of feedback in the progress indicator significantly affects user satisfaction. Progress indicators that provide feedback in terms of progress functions were felt to be significantly shorter and brought more user satisfaction than the repetitive function only indicating activity. The results indicate that user satisfaction is promoted by a high degree of feedback (in percent).

The summary of the Literature review performed can be categorized as below.

Table 5: Summary of the Literature Review-Part 1

Author	Problems Identified in Internal Storage	Conclusion
DAVIDAVIČIENĖ, 2020	The quality of the graphics is a huge factor contributing to the user experience and limited content reduces user experience.	Move the content to an external server
LIU et al., 2014	MAR imposes severe challenges on the limited battery capability of an always-on mobile device.	Cloud mobile rendering approach
XIUQUAN QIAO et al., 2019	MAR applications are power-hungry and to give the user a proper experience, it puts tremendous pressure on the battery of the mobile device	Offload computing pressure to the cloud.

Table 6: Summary of the Literature Review-Part 2

Author	Area	Advantages of moving content from the device's internal storage
LIU et al., 2014	Cloud mobile rendering	• High scalability across various mobile platforms • Able to use the most advanced rendering technologies, without concern about computation constraints resulting in rich graphic content • Significantly less battery consumption than rendering is performed on the mobile device itself

Author	Area	Advantages of moving content from the device's internal storage
SIRIWARDHANA et al., 2019	MAR Cloud-based architecture	• Suitable for centralized applications used by a vast number of distributed users
QIN et al., 2021b	Dynamic content delivery facilities	• When product owners can control the content, they likely will perceive it as both easy to use and useful

Table 7: Summary of the Literature Review- Part 3

Author	Problems when content loading in a dynamic nature
SIRIWARDHANA et al., 2019	Bandwidth Challenge: The continuous image/video transmission occupies a large part of the network bandwidth, which has a bad impact on core networks Latency Challenge: An additional communication delay is added due to the data transmission, and an unstable wireless environment also aggravates the performance of AR applications
Xiuquan QIAO et al., 2019	Large latency cannot meet high interactive demands, and this will lead to poor user experience
LIU et al., 2014	The user experience of CMR applications can be determined by graphic quality, video quality, and response time
YU et al., 2020	Relationship between response time and user experience Response time negatively affects users' tolerance, acceptance, and satisfaction

Table 8: Summary of the Literature Review- Part 4

Author	Existing solutions for enhancing user experience while content loading in mobile apps.	Conclusion
WANG et al., 2021	Design loading symbols and interfaces to improve users' quality of experience Considered 4 types of initial loading pages including null, rotating circle, logo & combination for measuring user experience on waiting time mental state & waiting time behavior.	A combination, of a logo plus a slogan, identified as the most prominent solution
Willermark et al., 2021	Considered the importance of progress indicator design in mobile applications concerning user interaction and satisfaction Compared the repetitive, linear, and percentage progress indicated	The "percent" progress indicator had higher user satisfaction.

The literature review identified problems/limitations when content loading in a dynamic nature and discussed the user experience enhancement methods for mobile apps. However, there is no research conducted specifically to capture and enhance the user experience while content is being loaded dynamically.

CHAPTER 3

METHODOLOGY

The main aim of this research project is to study and enhance the user experience in Mobile Augmented Reality (MAR) applications when content is loaded to the screen dynamically. This scenario is hoping to be evaluated according to Three steps.

- Step 1: Review commonly used cloud bas MAR applications.

Under step 1, hoping to study and evaluate the experience in already existing MAR applications like “Blippar” when relevant content is loaded onto the screen. The step-by-step process of these applications will be analyzed, and a comparison of user experiences will be made. Also, the pros and cons of their user experience enhancements will be further analyzed to have a better understanding of it.

- Step 2: Built a MAR prototype without any user experience enhancements based on the case scenario and evaluated the application through interview-based questionnaires from people.

To evaluate the research problem, the Prototype MAR application was built without using any user experience enhancements as a case scenario. This prototype can identify a target and load relevant content/s dynamically through an external server (Cloud). This relevant content includes Text, Image, and Video. Using this prototype, examined the user experience when different types of content is loaded to the screen, through a questionnaire from selected participants. Participants filled out the questionnaire for the 3 types of contents separately. Then, according to the results from the questionnaire, the comparison is made using an ANOVA study to know whether there is any significant difference between the results for selected content types.

For this experiment, tried to minimize the possible effects of Mobile Performance, and network quality from affecting the results. Two indicators are hoped to be used mainly to examine the user experience of the prototype when the content is being loaded dynamically from an external server.

1. Attention: Check the ability of the MAR prototype to keep the awareness of the user while content is being loaded to the screen. Values ranging from Distracted (1) to Focused (5) will be used to verify the user experience in this criterion.
2. Satisfaction: Check the ability of the MAR prototype to fulfill expectations or the pleasure of the user while content is dynamically loaded onto the screen. Values ranging from Unsatisfied (1) to Very Satisfied (5) will be used to verify the user experience in this criterion.

The purpose of taking a rating is to perform ANOVA tests and post hoc Tests to find out whether there is a difference in the collection of results.

Also, Suggestions from the users will be collected to develop a better understanding of the importance of improving user experience.

- Step 3: Enhance the existing prototype based on the user experience and their suggestions.

Under step 3, with the suggestions from the interview-based questionnaire and literature, a few scenarios will be developed with different user-enhancing experiences. After that, another interview-based questionnaire will be conducted using the same set of people to analyze the improvements in the user experience according to different enhancements, and finally, a comparison will be formed using case scenarios and scenarios developed under step 3.

As shown in Figure 13, the methodology of this research can be summarized.

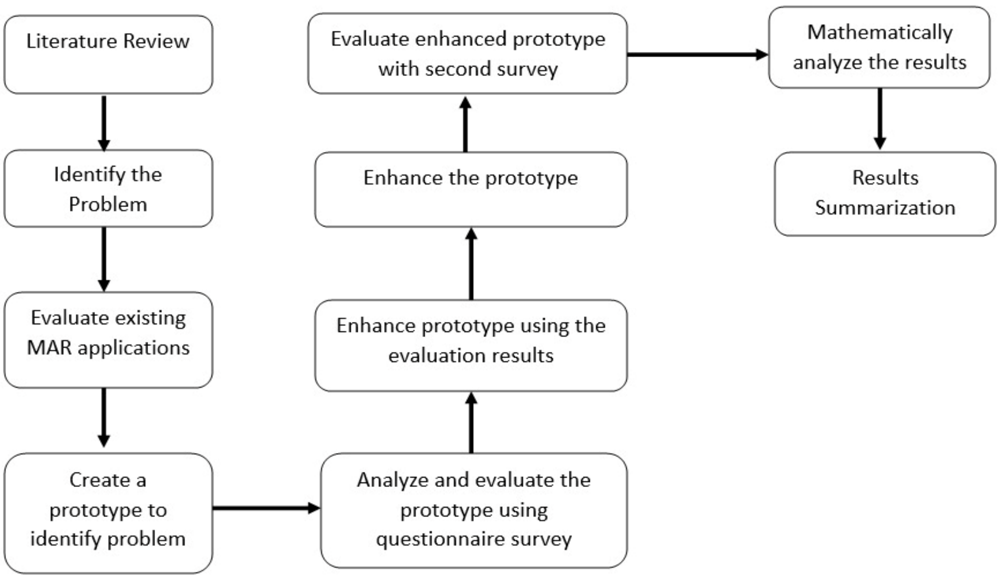


Figure 13: Research Process

3.1 Review of commonly used cloud-based MAR applications.

- **Blippar** [13]

Blippar is one of the commonly used cloud and marker-based MAR applications. It works with many global brands, businesses, institutions, and educational establishments to make valuable augmented reality experiences for its users.

Figure 14 shows a graphical representation of how the Blippar application works when a person uses it for the first time.

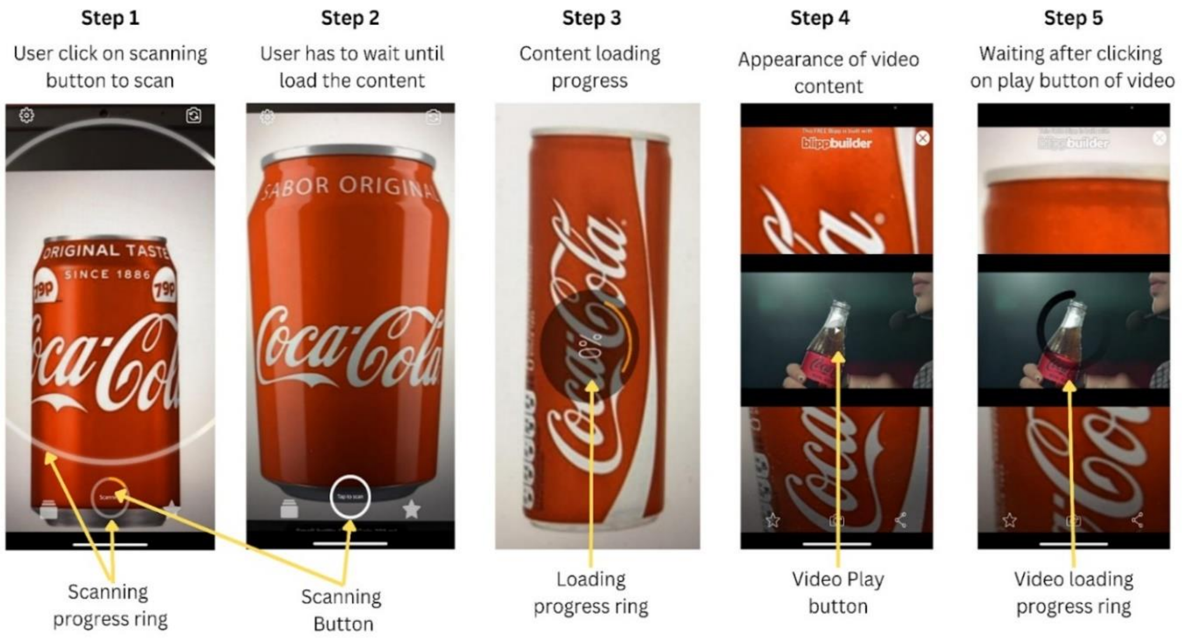


Figure 14: Step-by-step process of Blippar application for a first-time

The application starts the target identification process after the user puts the camera in front of the target and clicks the 'Tap to scan' button. Then, a progress ring appears to show the scanning process approximately, and it takes about 8 seconds (between step 1 and step 2). After that, the user needs to wait some time until the content is loaded. There is a progress ring to show content loading progress and the application lets the user know there is progress. But there is a gap between step 1 and step 2 and that gap affects the user experience since the user does not know whether there is content to load or not. Users may move the phone aside by thinking there is no content at that time. Hence, there is a requirement there to keep user interaction with the mobile app until content is loaded to the mobile device. Also, After the video content appears, the user needs to click the play button to play video content. But, yet again the user must wait approximately 6 seconds until the video starts playing. Table 9 summarizes the results of the analyzation

Table 9: Comparison of loading time of the application for different brands

Scanning product	**Trial**	**Is content being load scanning time?**	**Scanning Time of Step 1**	**The gap between Step 1 and Step 2**	**Content loading time in Step 3**	**Content type**	**Loading time in step 5 (Video content)**
Coca Cola	1	No	8s	1s	7s	Video	8s
	2	Yes	6s	-	6s		6s
Pepsi	1	No	8s	1s	4s	GIF	
	2	Yes	5s	The content displayed without waiting	4s		-
Toblerone	1	No	8s	1s	6s	2D Image	-
	2	Yes	4s	The content displayed without waiting	1s		-
Samsung	1	Yes	6s	The content displayed without waiting	1s	2D Image	-
	2	Yes	4s		3s	3D images	-
	3	Yes	2s		-	3D text	-

Issues facing in the current application when someone uses it for the 1st time:

- There is a time gap between step 1 and step 2 and the user is not notified of what is occurring.
- If there is no content to be loaded for the target object, the user doesn't get any notification.
- There are 4 waiting steps in the explained scenarios above and doesn’t handle proper ways to keep user experience.

These kinds of issues can be addressed in similar applications to this as well.

3.2 Preparation of the first prototype without using any enhancements as the initial Condition

As mentioned before, after the analysis of currently available MAR applications, a Test Module is developed without any enhancements to improve the user experience. This is the initial condition of the analysis. This prototype can identify a target and load relevant content/s dynamically through an external server (Cloud). For the test module 1, Text, image, and video were selected as 3 types of content to capture the user experience according to the varying content sizes. The purpose of doing this is to analyze the user experience variation according to the content sizes and its effect on the content loading time.

3.2.1 Technologies used for developing the prototype

The development of Mobile applications is carried out with the following technologies. The "Vuforia" development kit is for identifying targets and the "Unity 3D" tool is used for rendering 3D models and building the application. Additionally, the "Firebase" database is used the store the text, image, and video contents. Finally, the Android SDK toolkit is used for improving interaction with the mobile device.

- **Vuforia Engine (10.21)**

Vuforia SDK is a popular AR software development kit that employs advanced computer vision techniques to detect and track marks by analyzing the camera's target features. Vuforia object recognition can recognize complex 3D objects and it offers a cloud database for storing target images.

- **Unity 3D (2021.3)**

Unity 3D is a cross-platform integrated game engine that enables developers to develop 2D and 3D games based on mobile devices with the support of C# and C++ programming languages. Unity is chosen for creating and implementing MAR test module development over other platforms due to the extendibility and simplicity of the Unity software.

- **Firebase**

Firebase is a set of backend cloud computing services and application development platforms provided by Google. It hosts databases, services, authentication, and integration for a variety of applications, including Android, Unity, and C++.

  - Cloud Firestore - Use our flexible, scalable NoSQL cloud database, built on Google Cloud infrastructure, to store and sync data for client- and server-side development.
  - Cloud Storage - Built on fast and secure Google Cloud infrastructure for app developers who need to store and serve user-generated content, such as photos or videos.

- **Android SDK**

Android SDK toolkit is used to convert the Unity project file to Android, which is simply the purpose of converting the computer project to a mobile application.

- **Visual Studio**

This is a Tool used for programming movements in 3D models, as well as sequencing the activities of the application.

- **C# language**

Object-oriented scripting language which the function of scenes was programmed to be invoked by unity.

- **Contents**

Videos, Images, 3D Models, and audio are used as content directly downloaded from websites that provide those for free.

- **Mobile Phone**

It allows interaction, both with the application with AR (projection) and the scanning of the real environment through the mobile camera (image scanning). For optimal performance of the application, the Android version must be considered on the mobile, it must be 8.1 or later.

- **Application Architecture**

Figure 15 is a graphical representation of the Application architecture created for the benefit of this research.

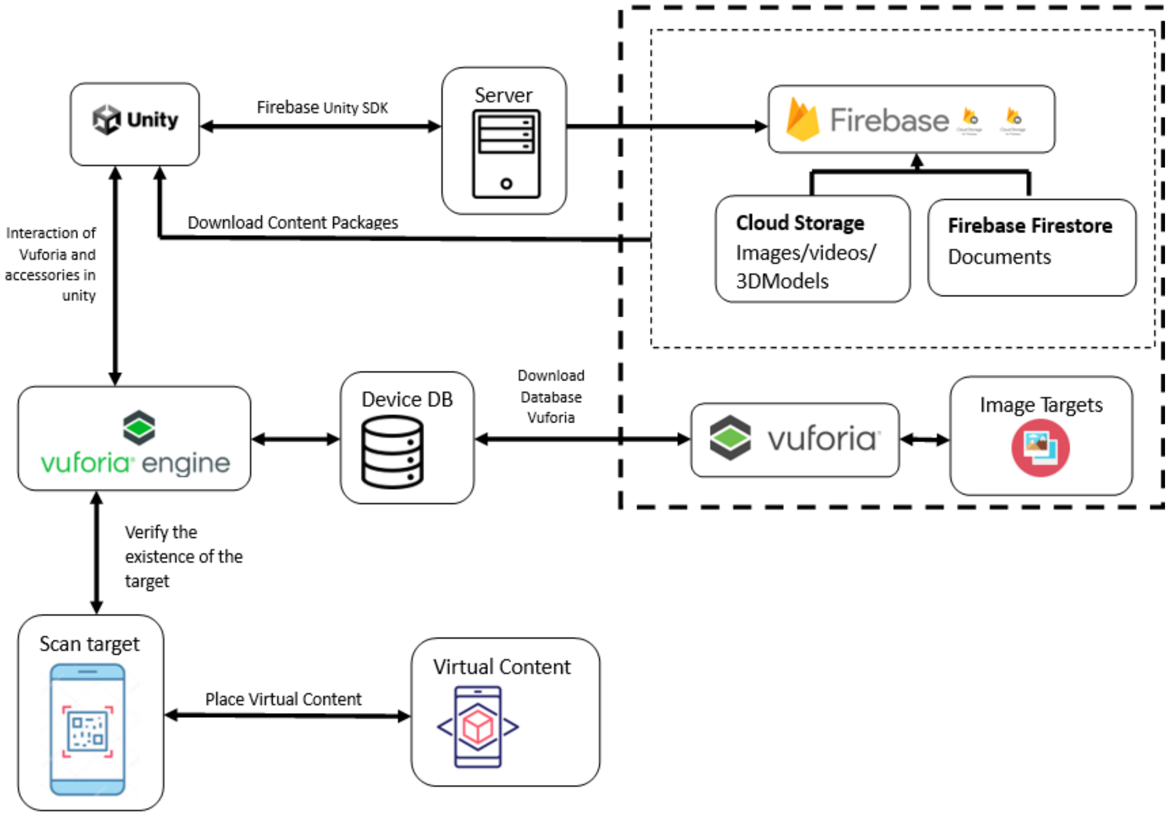


Figure 15: Application architecture

First, when the user scans the target using a mobile device camera, the frames taken from the device camera are sent to the Vuforia SDK. Vuforia recognizes and tracks flat images in real time using a specific AI-enabled vision technology. Then the system identifies the content package for the target and sends a request to get the content from the external server. After that, the Server will send a download request to the cloud Firebase database and download the content package to the device. Unity application will place the downloaded virtual content on top of the image target.

3.2.2 Development of a Prototype without any enhancements

As mentioned above, the “AR test module” prototype has been developed on Android using Unity 3D. As shown in Figure 16, Unity 3D develops gaming prototypes that can be compiled following different platforms (PC, Mac, Web, IOS, Android, and Windows Phone) without any infrastructure changes. Here uses a minimum API level of 30.

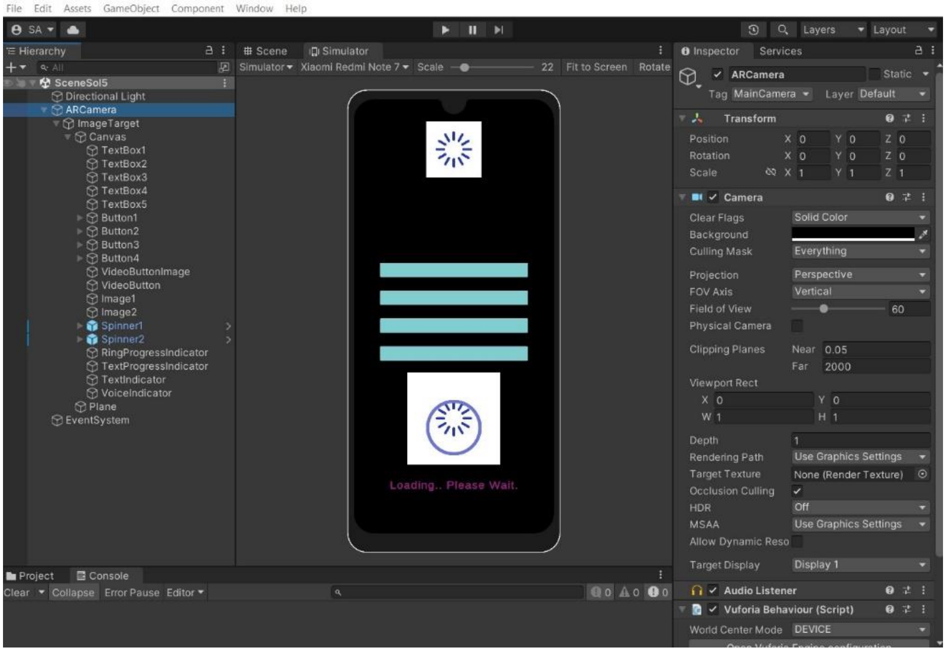


Figure 16: Developing prototype using Unity 3D

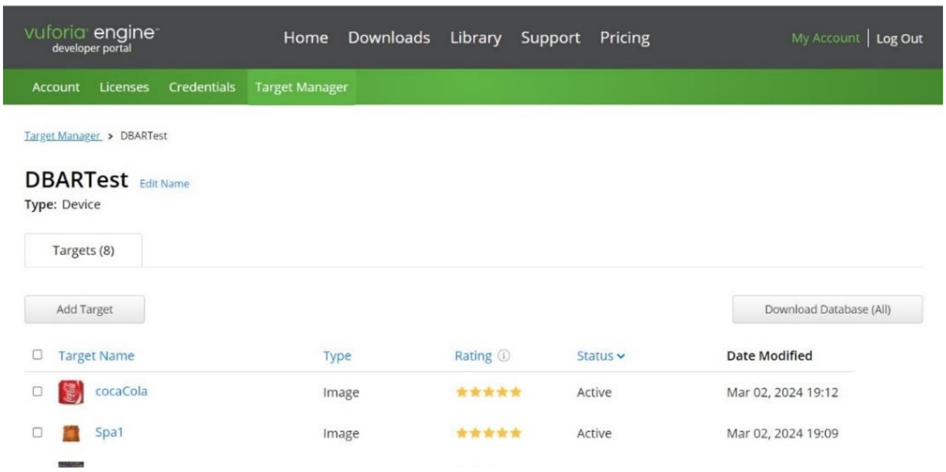


Figure 17: Vuforia Engine target manager database

A Vuforia database holds the information necessary to track various predefined targets in the form of dataset files. When the user scans the target using a mobile device, the frames taken from the device camera are sent to the Vuforia SDK. The pixel transformation procedure is applied to these frames and compared frames with the image targets in the Vuforia database. If taken frames are matched with one of the image targets in the Vuforia database, it is marked as identified as the target. Figure 17 shows the developed Vuforia Engine target management database used for creating the prototype.

Firebase Cloud Firestore is used for storing textual contents that are required to load dynamically in application run time. This is a NoSQL data model, that stores data in documents that contain fields mapping to values. Firebase storage is used to store content types such as images, audio, video, and content and download directly to the device. Here can access the content data via C sharp scripts in a unity development environment. Figure 18 show the Firebase Storage and Firebase Cloud Firestore used for creating the prototype.

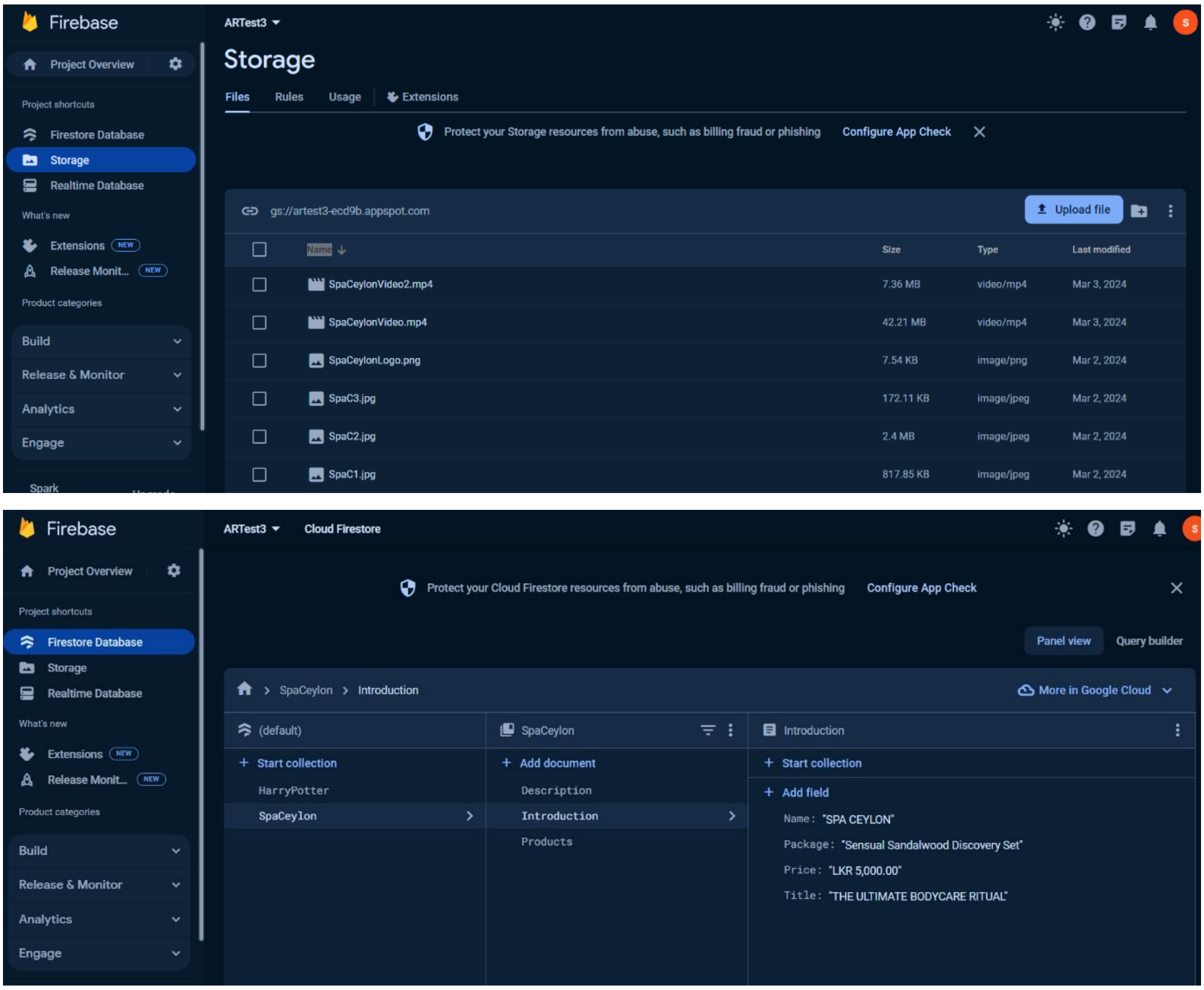


Figure 18: Fiirebase Storage

Figure 19 shows the step-by-step process of how the application works. In this prototype, 3 types of virtual content can be loaded into the screen when a user scans an object. They are Texts, Images, and Videos. The purpose of doing this is to analyze how the software handles the contents with different sizes and to analyze virtual content times accordingly. More details regarding the 3 content types used for the analysis are available in Table 10.

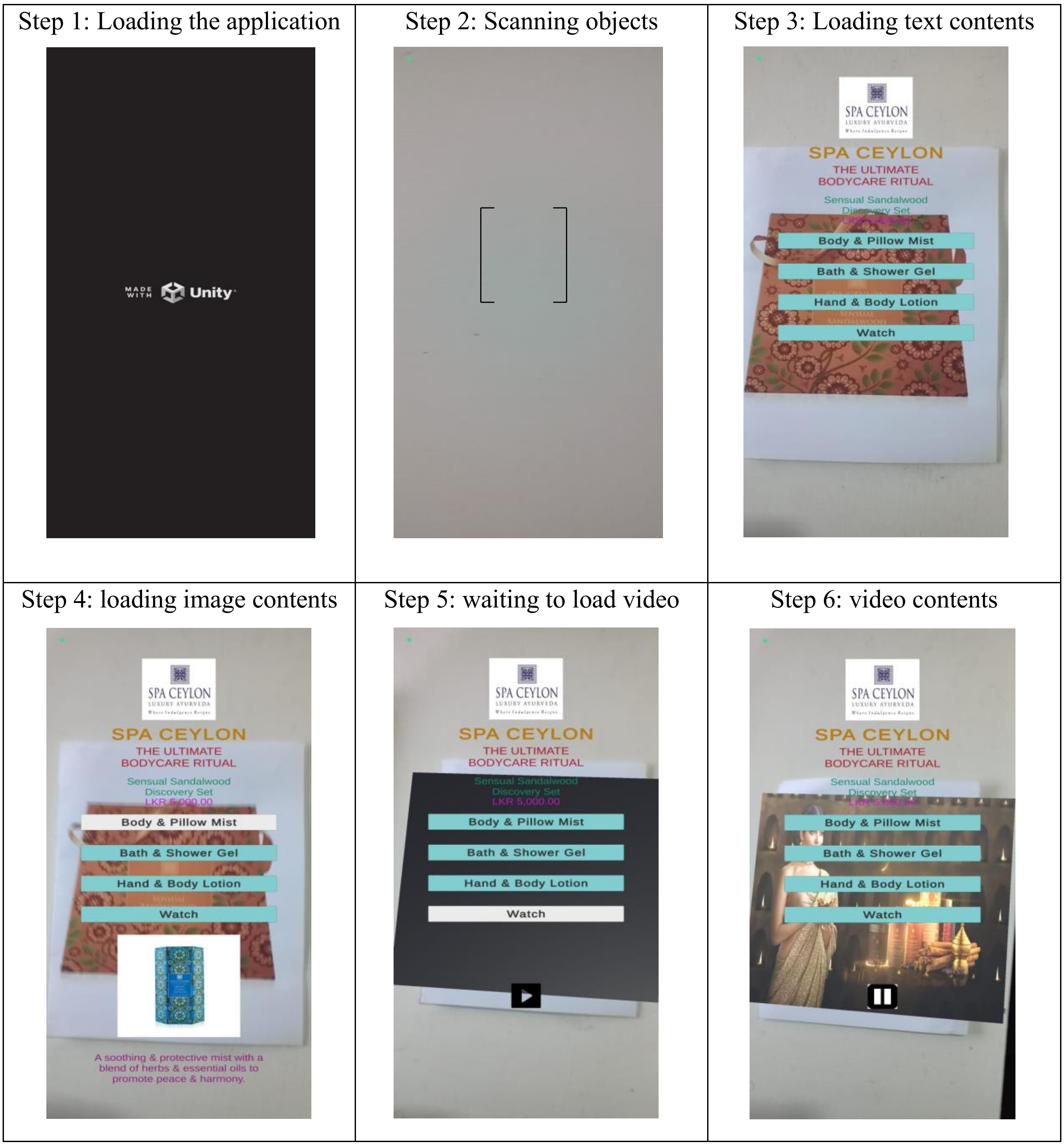


Figure 19: Prototype MAR app used for User Experience evaluation process

Table 10: Details of different content types

Content type	Content size	Approx. loading time
Text	10 KB	Less than 1s
Image	2.4 MB	2.5s -4s
Video	42.21 MB	More than 18s

3.3 Questionnaire-based survey to evaluate user experience of the first prototype

To evaluate the user experience of the MAR application's content loading time, an Ad hoc questionnaire is developed (shown in Figure 20 and described under Table 11) using Google Forms. This included questions such as their age, gender, familiarity with using Mobile Augmented Reality Applications, the usability of the developed prototype, and most importantly their own experience with virtual content loading time according to two main variables considered: Attention and Satisfaction. This questionnaire captured the user experience separately for the 3 content types used under the developed prototype. Hence, Analysis can be made on how the content sizes affect on user experience when content loading as well.

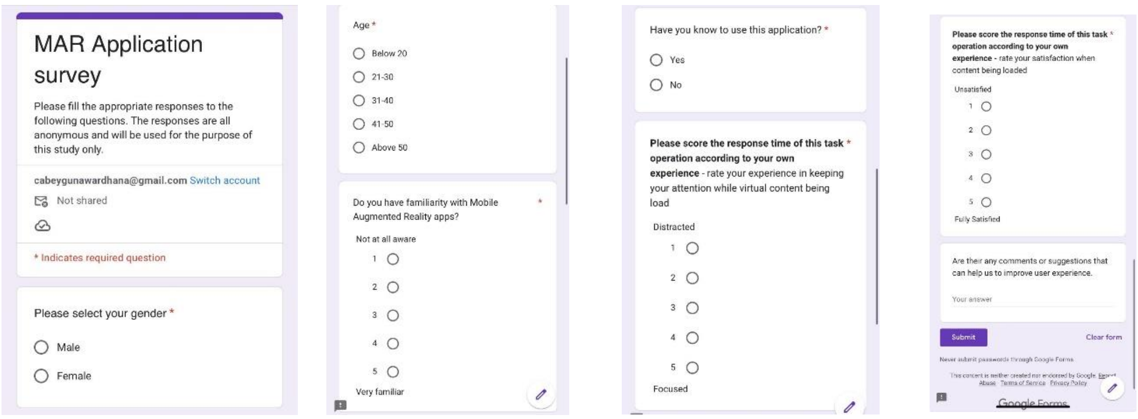


Figure 20: Ad hoc questionnaire for data collection – questionnaire 1

- **Ad hoc questionnaire:**

Table 11: Ad hoc questionnaire

No	Question	Answer selection criteria
1	Please select your Gender	Male or Female
2	Age	Below 20, 21-30, 31-40,41-50, Above 50
3	Do you have familiarity with Mobile Augmented Reality apps?	1 as not at all aware 5 is very familiar
4	Do you know how to use this application?	Yes or No
5	Please score the response time of this task operation according to your own experience - rate your experience in keeping your attention while virtual content is being loaded	1 as Distracted and 5 as focused
6	Please score the response time of this task operation according to your own experience - rate your satisfaction when content being loaded	1 as unsatisfied and 5 as fully satisfied
7	Are there any comments or suggestions that can help us to improve user experience?	Written input

An additional 20 participants were recruited (12 females and 8 males) who had not participated in this kind of experiment before to avoid possible learning effects. First, a brief introduction was given to the participants about the research purpose, how the application works, and the questionnaire. Then, developed a mobile AR application given to their respected mobile phones to have firsthand experience with the software. 20 participants are selected based on different Age spans intending to select people with different familiarities with MAR applications. Participants are not allowed to use Apple Devices since the app is not supported by the "iOS" system. They were mainly using mobile device brands like Samsung, Xiaomi, Oppo, and OnePlus which all run on Android platforms.

As mentioned above, the developed application has 3 types of virtual content loaded to be loaded. Hence, in the questionnaire, participants' answers were collected according to the 3 types of virtual content separately. The purpose of this is to analyze further how the user experience variable behaves according to the different virtual content sizes.

3.4 Development of prototypes using Enhancements according to the questionnaire-based evaluation and literature

After the user experience evaluation on content loading time separately for the 3 content types used, 5 prototypes were developed with different types of user experience enhancing methods as experimental stimuli to analyze improvement in user experience occurred after the enhancements used. These 5 types of user experience-enhancing methods for the loading interface are extracted from studying literature and analyzing common MAR applications. The literature review done under Chapter 2 states that these 5 prototypes have improved user-enhancing skills. (WANG et al., 2021) and (Willermark et al., 2021)

Five prototype scenarios with different user enhancement and a prototype without any enhancement methods are as follows. Table 12 shows the image representation of each enhancement method considered.

1. Without any Enhancements (Null):

This is taken as a base condition to check whether there are any improvements to user experience with implementing enhancement methods.

2. Loading Text:

Displaying a text message, “Loading…” by providing clear feedback to users that the system is actively working on their request.

3. Animated Icon:

Engaging animations or icons can be used to entertain users during the loading process. They add visual interest and make the waiting experience more enjoyable.

4. Progress indicator:

This type of indicator allows users to track the completion of the loading process.

- Progress circle: Represents the completion of a task or loading process using a circular shape that fills up gradually.
- Progress percentage: Displays the progress as a percentage, allowing users to track the completion of the loading process numerically.

Here, the first application identifies the size of content that needs to be loaded from the external storage. Then send a loading request and until that is complete track the completion of the task numerically concerning the content size.

5. Voice Indicator:

Displaying a voice message, “Loading…Please wait,” can provide clear feedback to users that the system is working on their request.

6. Hybrid Indicators:

Combination of Loading text, Voice indicator, progress circle, and progress percentage.

Table 12: Five types of initial loading scenarios

1. Without any  enhancements	2. Loading Text 	3. Animated icon 
4. Progress indicator 	5. Voice indicator 	6. Hybrid indicator 

3.5 Second questionnaire-based survey to evaluate the user experience of different prototypes

To evaluate 6 prototypes developed after the first questionnaire, another questionnaire was performed using the same set of participants. The purpose of this is to find out whether there is any improvement in using enhancement methods when content loads dynamically. This included questions such as their own experience with virtual content loading time according to two main variables considered: Attention and Satisfaction. Participants filled the questionnaire 5 times separately for each 5 prototypes without prototype 1 which they already commented on under the first questionnaire. Ad hoc questions are as follows.

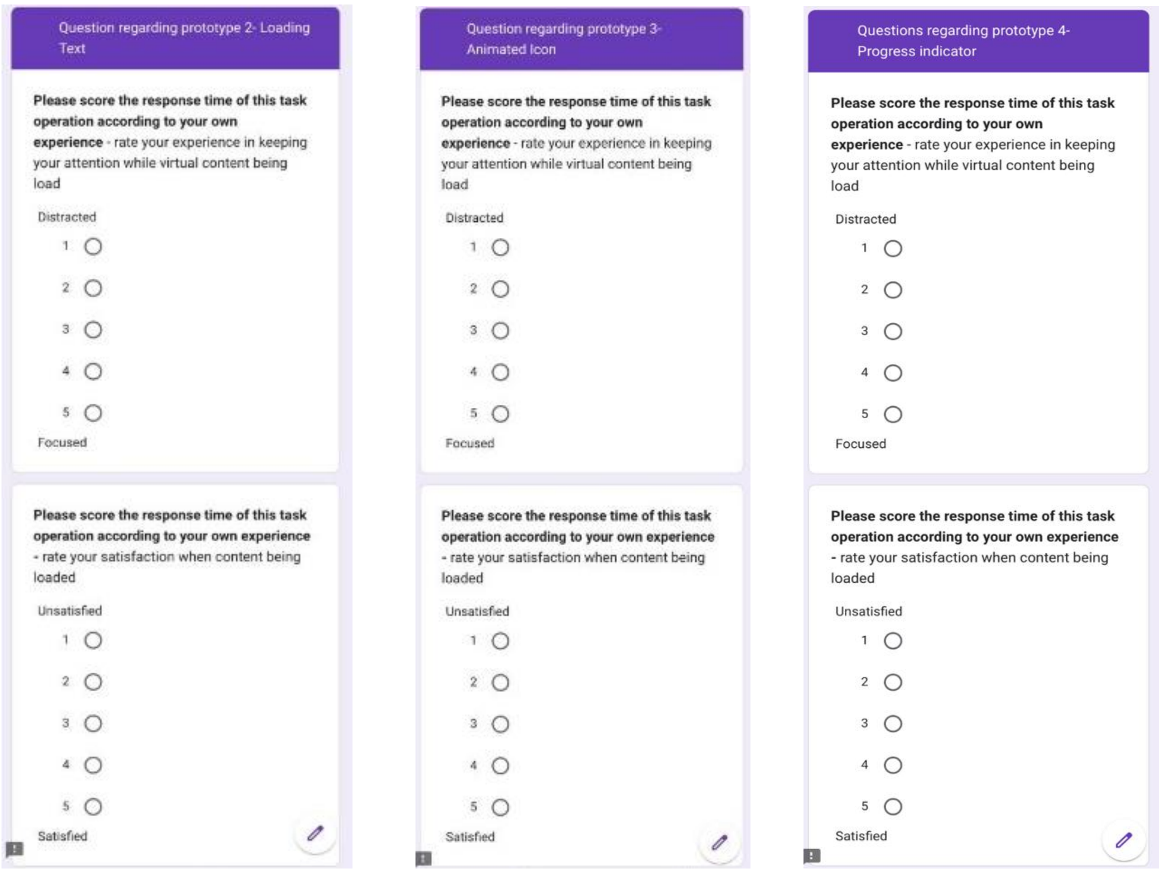


Figure 21: Ad hoc questionnaire for data collection – questionnaire 1 (part 1)

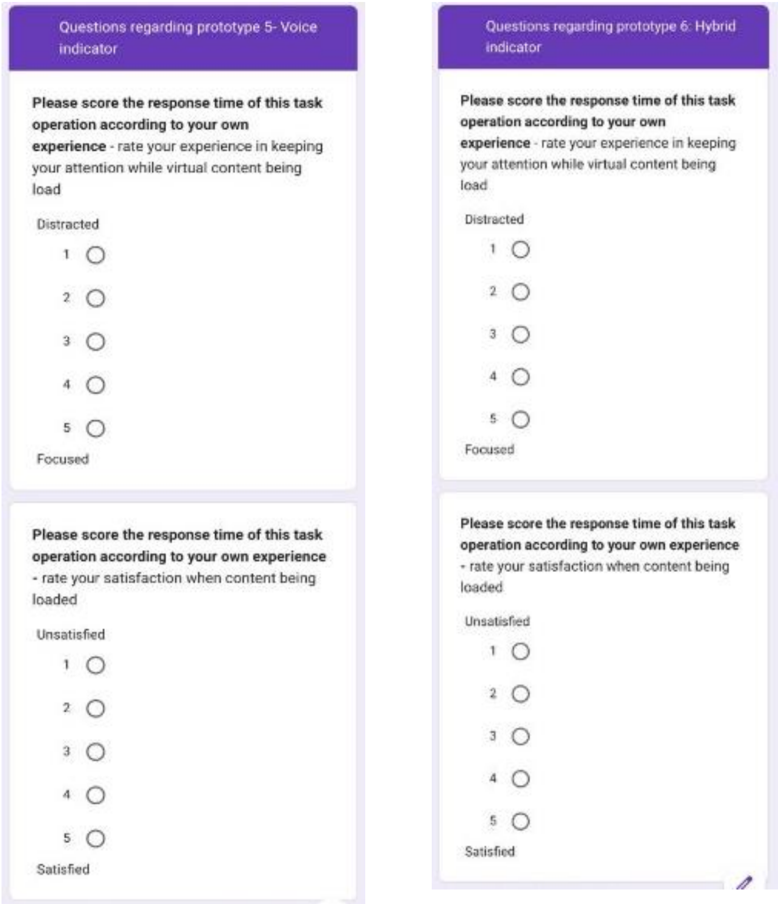


Figure 22: Ad hoc questionnaire for data collection – questionnaire 1 (part 2)

CHAPTER 4

EVALUATION AND RESULTS

To evaluate the User Experience in the MAR Application, developed a prototype application and had a user experience questionnaire using selected 20 participants using Ad hoc questions. With the suggestions from the interview-based questionnaire and literature, six scenarios were developed. Five of them are with different kinds of enhancements and one of them is without any enhancements as the base condition. After that, another interview-based questionnaire was conducted using the same set of participants to analyze the improvements in the user experience according to different enhancements.

4.1 Evaluating results from the first questionnaire on user experience

Results from the first questionnaire conducted for the prototype application with no enhancements are shown in Figure 24.

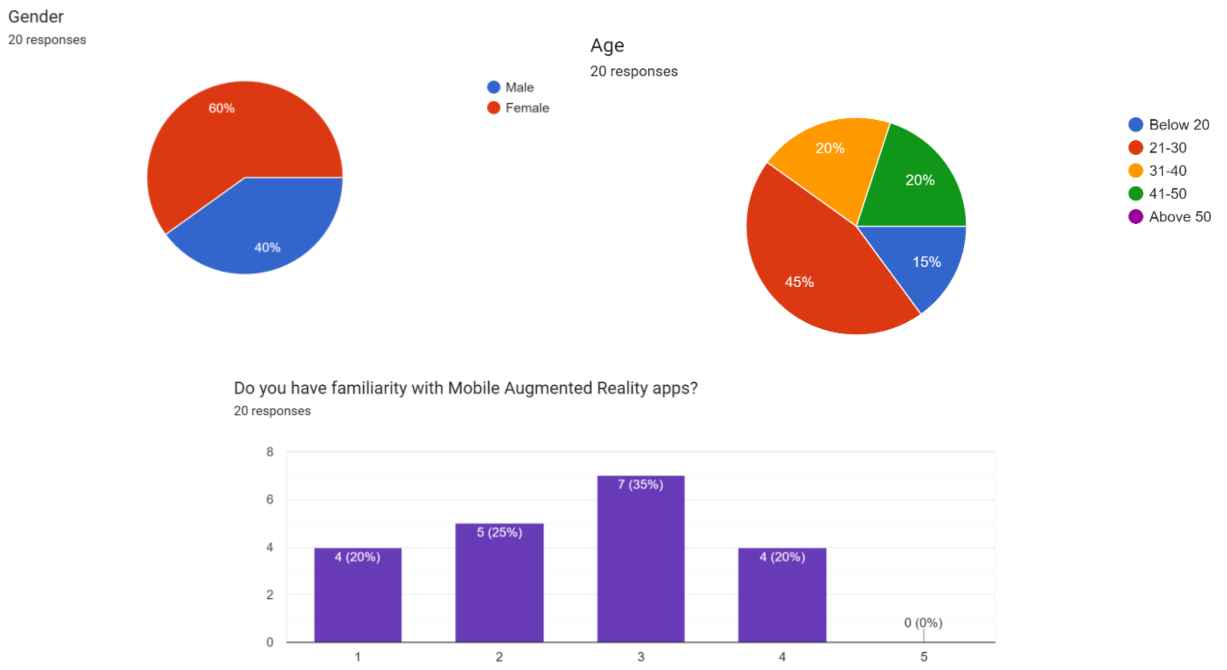


Figure 23: Gender, Age group and Familiarity with Mobile Augmented Reality Apps variation of the selected participants

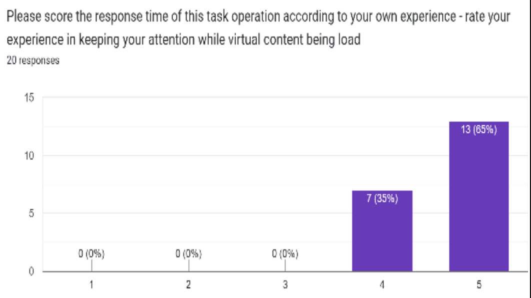
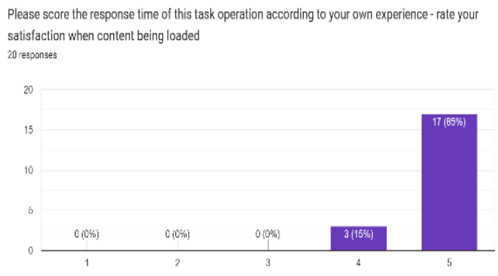
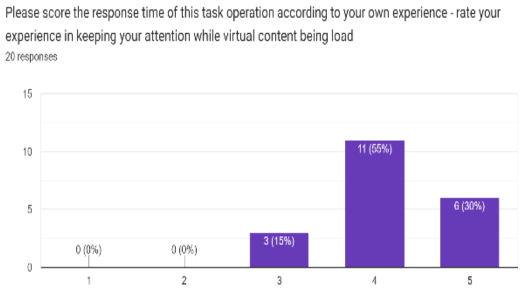
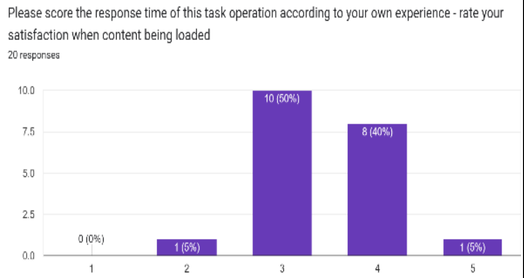
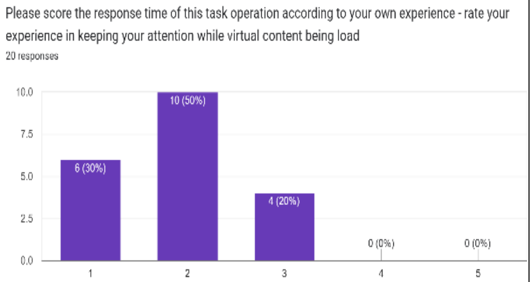
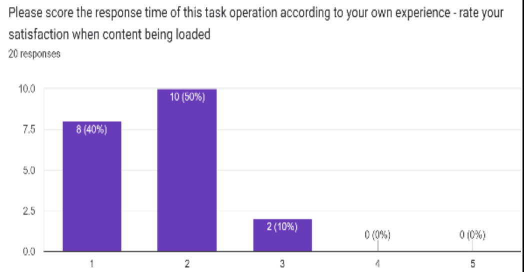
Content type	User Experience according to the "Attention"	User Experience according to the "Satisfaction"
Text		
Image		
Video		

Figure 24: Questionnaire Results and Statistical Analysis

It is observed that text content loaded within less than 1s. Hence, it is not necessary to continue to go ahead with enhancing it.

Following are some of the participants' comments regarding the user experience and how to improve it.

- Better to introduce progress indicators while loading content. Unless hard to identify some content will going to load.
- Add a scan icon while scanning the relevant target.
- Show the system status when identifying the target and loading content. Otherwise, it's hard to identify what is going on.
- If the content load is taking a long time to load, add a mini-game.
- Add some text or message while loading the content.
- Hard to keep attention for a long time while loading content.

To compare the impacts of the results according to three content types first, a one-way ANOVA test and after that Post-hoc Test using Bonferroni correction was performed. For the one-way ANOVA test, the following two hypotheses were formulated.

- Null Hypothesis (H0): There is no significant difference between the means of the results of three content types
- Alternative Hypothesis (H1): There is a significant difference between means of the results of three content types

Using Microsoft Excel, one-way ANOVA tests were performed according to the three content type categories for Variables Attention and Satisfaction separately. Following Table 13 and Table *14* are the results of one-way ANOVA tests. Please consider that the p-value for one-way ANOVA tests is taken as 0.05.

Table 13: One-way ANOVA test result according to the variable Attention

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Text	20	93	4.65	0.239474
Image	20	83	4.15	0.45
Video	20	38	1.9	0.515789

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	85.83333333	2	42.91667	106.8231	5.24E-20	3.158843
Within Groups	22.9	57	0.401754			
Total	108.7333333	59				

Table 14: One-way ANOVA test result according to the variable Attention

SUMMARY

Groups	Count	Sum	Average	Variance
Text	20	97	4.85	0.134211
Image	20	69	3.45	0.471053
Video	20	34	1.7	0.431579

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	99.63333333	2	49.81667	144.1396	5.06E-23	3.158843
Within Groups	19.7	57	0.345614			
Total	119.3333333	59				

According to the results from One-way ANOVA Tests performed, both p values are less or equal to 0.05. Hence, neglect the Null Hypothesis and take the Alternative Hypothesis as true. This means there is a significant difference between the means of the results of the three content types.

After that, post-hoc Tests using Bonferroni correction were performed separately for variables Attention and Satisfaction to identify which content type (Text, Image, or Video) results are significantly different from others. Results from post-hoc Tests are shown in Table 15 and Table 16.

Table 15: post-hoc Test for Variable "Attention"

POST-HOC TEST

Groups	P Value (T-Test)	Significant ?
Text vs Image	0.0194267	No
Text vs Video	9.92551E-17	Yes
Image vs Video	1.76377E-12	Yes

ALPHA

Test	Alpha
ANOVA	0.05
Post-hoc Test (Bonferroni corrected)	0.016667

Table 16: post-hoc Test for Variable "Satisfaction"

POST-HOC TEST

Groups	P Value (T-Test)	Significant ?
Text vs Image	0.09558934	No

ALPHA

Test	Alpha
ANOVA	0.05

Text vs Video	8.76061E-21	Yes
Image vs Video	5.57273E-10	Yes

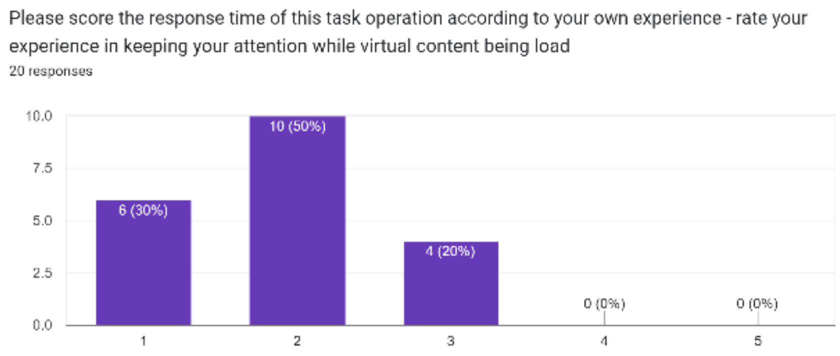
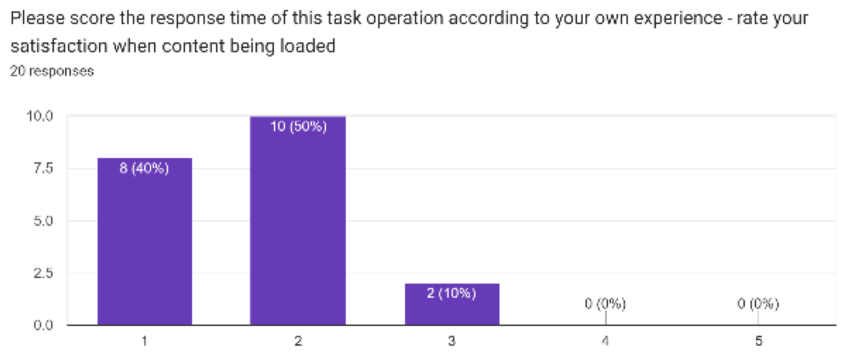
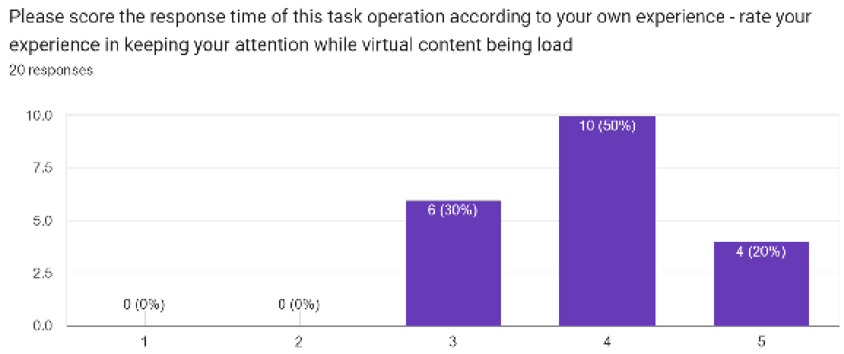
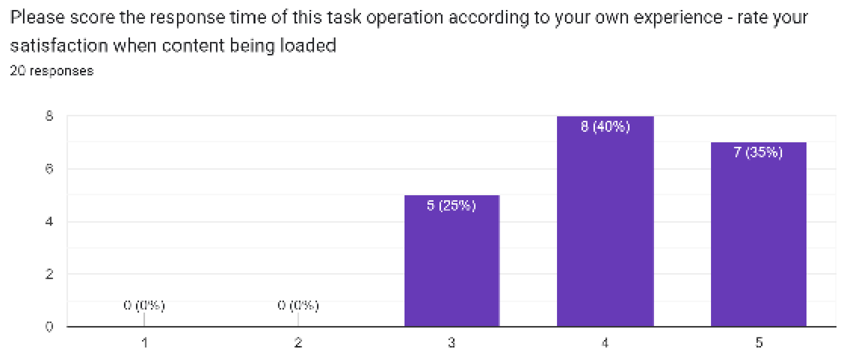
Post-hoc Test (Bonferroni corrected)	0.016667

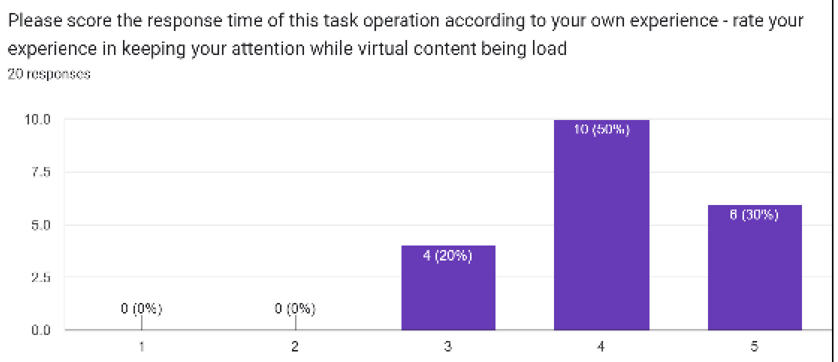
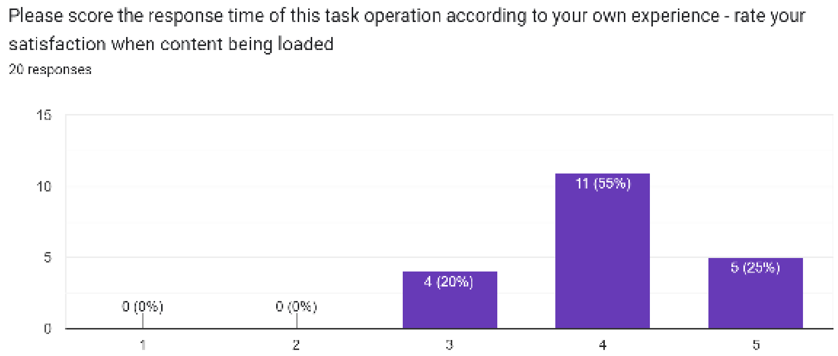
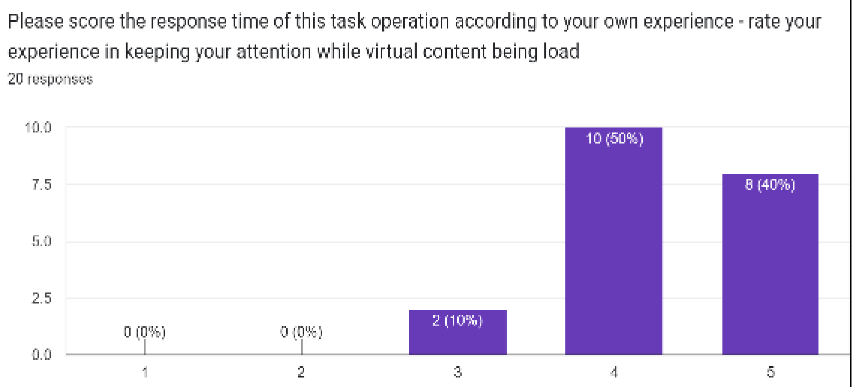
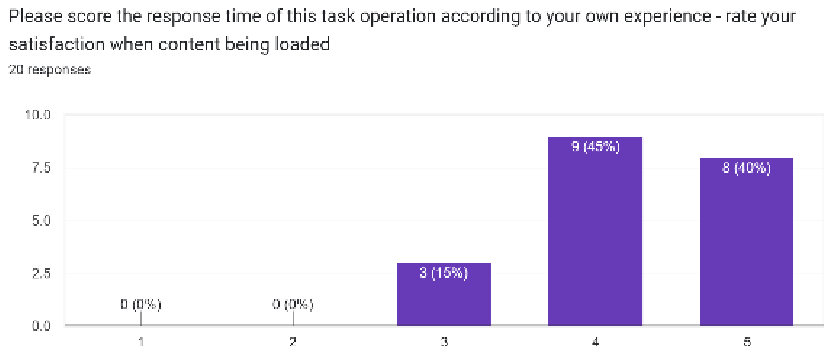
Hence, the conclusion from the POST-HOC Test clearly states that there is a significant difference in results between the comparison of Text vs Video and Image vs Video for both variables. For both those comparisons, Video content type is constant. Hence, it can be concluded that the difference in the results lies in the results for Video content. But, it takes the means of the values variables Attention and Satisfaction into account, Video content has a lesser mean (1 for less attention or satisfaction and 5 for higher attention or satisfaction) compared to other content types. Hence, according to the above calculations, can be concluded that results from the user experience questionnaire show participants show less attractiveness and satisfaction when video content loads dynamically.

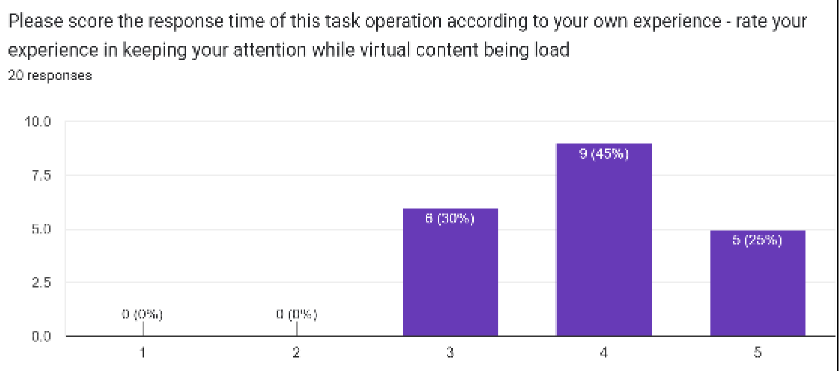
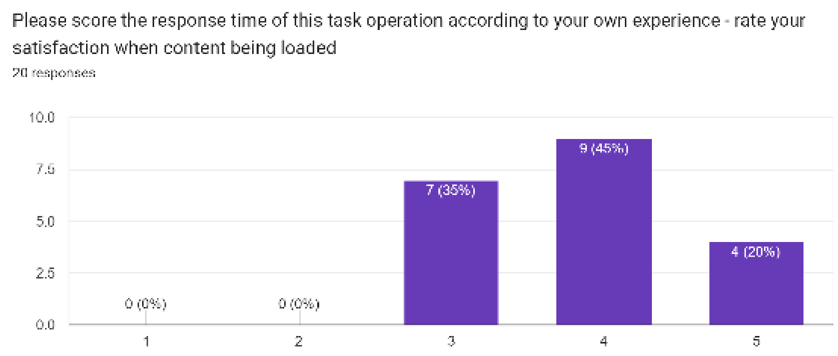
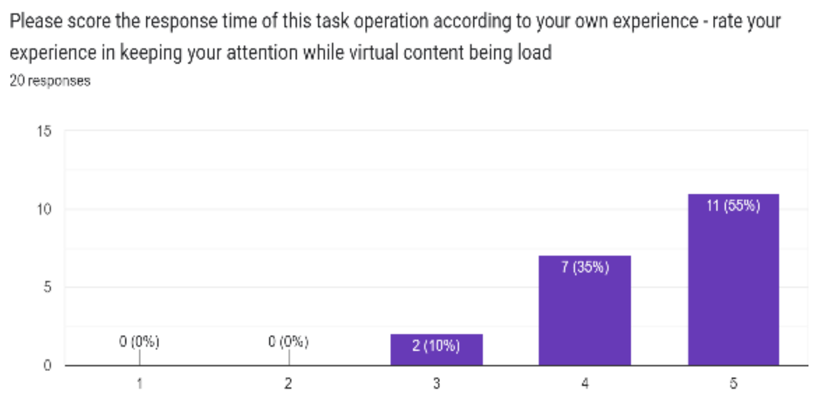
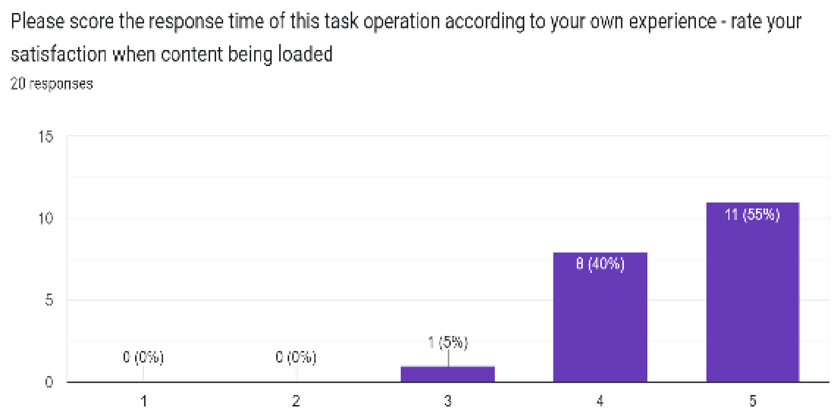
4.2 Evaluating results from the second questionnaire on user experience

Results from the second questionnaire conducted for the prototype application with no enhancements are shown in Table 17.

Table 17: Questionnaire Results and Statistical Analysis

Prototype	User Experience according to the “Attention”	User Experience according to the “Satisfaction”
1		
2		

Prototype	User Experience according to the “Attention”	User Experience according to the “Satisfaction”
3		
4		

<table>
<tr><th>Prototype</th><th>User Experience according to the “Attention”</th><th>User Experience according to the “Satisfaction”</th></tr>
<tr><td>5</td><td>
</td><td>
</td></tr>
<tr><td>6</td><td>
</td><td>
</td></tr>
</table>

To compare the impacts of the results according to six prototypes, again one-way ANOVA test and after that Post-hoc Test using Bonferroni correction were performed. For the one-way ANOVA test, the following two hypotheses were formulated.

- Null Hypothesis (H0): There is no significant difference between means of the results of six prototype's user experiences
- Alternative Hypothesis (H1): There is a significant difference between means of the results of the six prototype user experiences

Following Table 18 and Table 19 are the results of one-way ANOVA tests. Please consider that the p-value for one-way ANOVA tests is taken as 0.05.

Table 18: One-way ANOVA test result according to the variable Attention

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Prototype 1	20	38	1.9	0.515789
Prototype 2	20	78	3.9	0.515789
Prototype 3	20	82	4.1	0.515789
Prototype 4	20	86	4.3	0.431579
Prototype 5	20	79	3.95	0.576316
Prototype 6	20	89	4.45	0.471053

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	87.96667	5	17.59333	34.8807	1.69E-21	2.293911
Within Groups	57.5	114	0.504386			
Total	145.4667	119				

Table 19: One-way ANOVA test result according to the variable Satisfaction

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Prototype 1	20	34	1.7	0.431579
Prototype 2	20	82	4.1	0.621053
Prototype 3	20	81	4.05	0.471053
Prototype 4	20	85	4.25	0.513158
Prototype 5	20	77	3.85	0.555263
Prototype 6	20	90	4.5	0.368421

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	104.7417	5	20.94833	42.45529	1.66E-24	2.293911
Within Groups	56.25	114	0.493421			
Total	160.9917	119				

According to the results from One-way ANOVA Tests performed, both p values are less or equal to 0.05. Hence, neglected the Null Hypothesis and take the Alternative Hypothesis as true. This means there is a significant difference between means of the results of user experiences in six prototypes.

After that, post-hoc Tests using Bonferroni correction were performed separately for variables Attention and Satisfaction to identify which prototype user experience results are significantly different from others. Results from post-hoc Tests are shown in Table 20 and Table 21.

Table 20: Post-hoc test for Variable "Attention"

POST-HOC TEST

Groups (Prototype vs Prototype)	P Value (T-Test)	Significant?
1 vs 2	1.03228E-10	Yes
1 vs 3	8.20206E-12	Yes
1 vs 4	2.10461E-13	Yes
1 vs 5	1.13898E-10	Yes
1 vs 6	6.44138E-14	Yes
2 vs 3	0.384053705	No
2 vs 4	0.073908798	No
2 vs 5	0.8317145	No
2 vs 6	0.017855627	No
3 vs 4	0.363925253	No
3 vs 5	0.524785393	No
3 vs 6	0.123396817	No
4 vs 5	0.127261992	No
4 vs 6	0.484448037	No
5 vs 6	0.035131477	No

ALPHA

Test	Alpha
ANOVA	0.05
Post-hoc Test (Bonferroni corrected)	0.003333

Table 21: post-hoc Test for Variable "Satisfaction"

POST-HOC TEST

Groups (Prototype vs Prototype)	P Value (T-Test)	Significant?
1 vs 2	9.60313E-13	Yes
1 vs 3	1.92062E-13	Yes
1 vs 4	3.36048E-14	Yes
1 vs 5	8.38818E-12	Yes
1 vs 6	1.4008E-16	Yes
2 vs 3	0.8317145	No
2 vs 4	0.532540989	No
2 vs 5	0.309130604	No

ALPHA

Test	Alpha
ANOVA	0.05
Post-hoc Test (Bonferroni corrected)	0.0033 33

2 vs 6	0.080070204	No
3 vs 4	0.37296271	No
3 vs 5	0.382849415	No
3 vs 6	0.034231408	No
4 vs 5	0.091632471	No
4 vs 6	0.241133014	No
5 vs 6	0.004446777	No

According to the above POST-HOC Tests performed using results from the user experience questionnaire, it is noticeable that the comparison between prototype 1 and all other prototypes has a significant difference in p-value. This means that the Prototype 1 user experience is significantly difference from the other five prototypes. Also, according to the results from Table 17, it is visible that participants have answered prototype 1 negatively according to the two variables.

Hence, according to the above calculations, the conclusion can be stated that the user experience questionnaire shows participants show less attractiveness and satisfaction when video content loads dynamically without any enhancements (for prototype 1).

Figure 25 and Figure 26 shows how the average of the questionnaire marks given by the participants changes according to six prototypes developed. It is noticeable that the prototype with "Null" Enhancements gets lesser marks for both variables "Attention" and "Satisfaction" with the prototype with "Hybrid" indicator getting Higher attraction from the users.

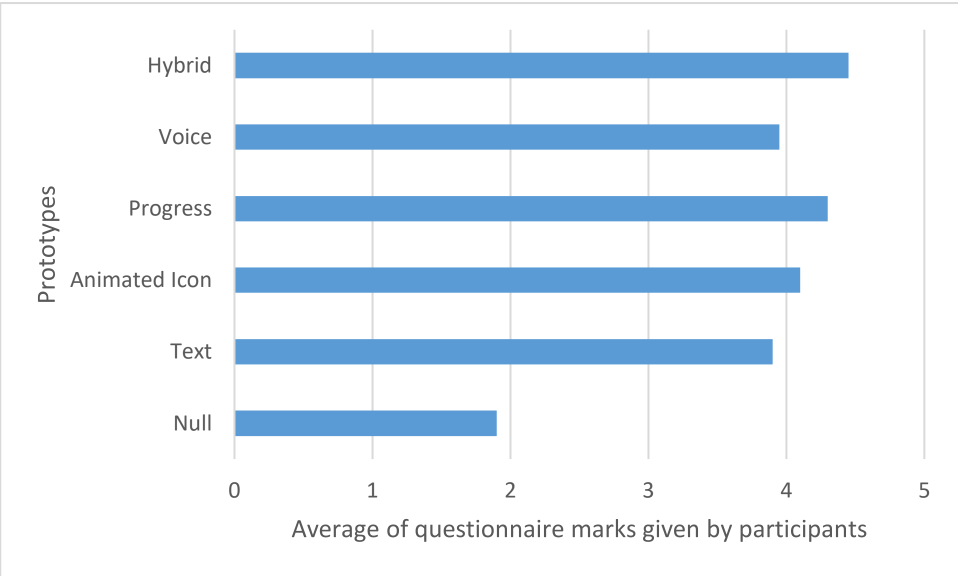


Figure 25: Comparison of the average results from the questionnaire according to the variable "Attention"

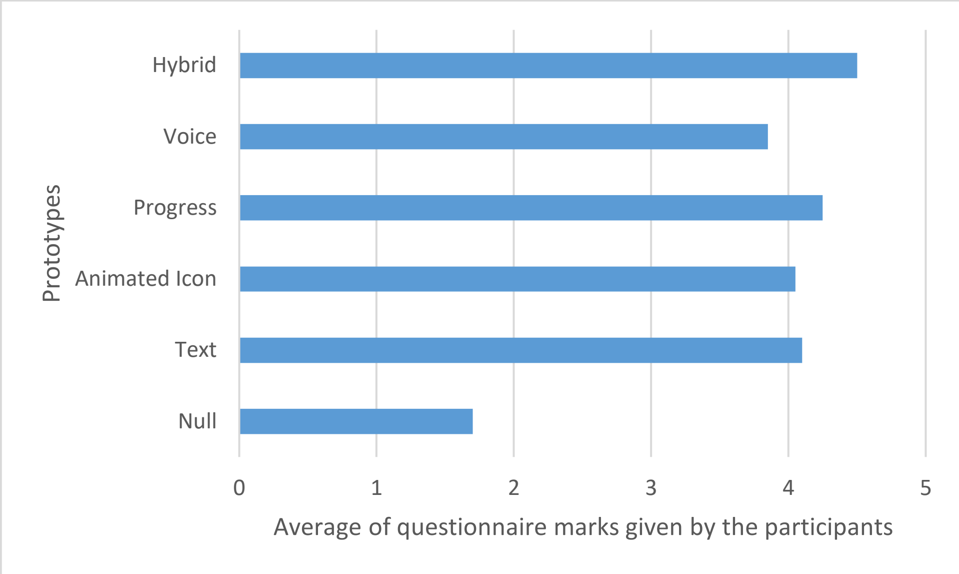


Figure 26: Comparison of the average results from the questionnaire according to the variable "Satisfaction"

Yet another comparison was made between the Hybrid prototype vs all other enhanced prototypes separately to analyze whether there is a significant difference between them. To compare the impacts of the results, again one-way ANOVA test was performed. For the one-way ANOVA test, the following two hypotheses were formulated.

- Null Hypothesis (H0): There is no significant difference between means of the results of Hybrid prototype and the other enhanced prototype considered
- Alternative Hypothesis (H1): There is a significant difference between means of the results of Hybrid prototype and the other enhanced prototype considered

Following Table 22 is the summary of results of the one-way ANOVA tests. Please consider that the p-value for one-way ANOVA tests is taken as 0.05.

Table 22: Comparison of the results from the ANOVA Test for each combination

Comparison	p value		Difference is Significant?	
	Attention	Satisfaction	Attention	Satisfaction
Hybrid vs Text	0.01786	0.08007	YES	NO
Hybrid vs Animated Icon	0.12340	0.07423	NO	NO
Hybrid vs Progress Bar	0.48445	0.24113	NO	NO
Hybrid vs Voice	0.03513	0.00445	YES	YES

According to the results from above Table *22* shows that there is a significant difference between the means of the results given by participants for Hybrid and Voice Prototypes for both variables “Attention” and “Satisfaction”. Hybrid vs Text comparison shows Significant Difference of the means of result according to the “Attention” Variable only. But, according to the Figure 25 and Figure *26*, it can be noted that Hybrid prototype is the most favorite enhancement methods among the participants. Hence, another conclusion can be stated as, that the Voice Enhanced Prototype is the least favorite among the participants and it is significant compared to the Hybrid Prototype.

CHAPTER 5

CONCLUSION

Augmented Reality (AR) is defined as the technology and methods that combine real-world objects and computer-generated content. With the proliferation of mobile devices, Mobile Augmented Reality (MAR) has emerged as the most popular and most convenient form of augmented reality. MAR applications can be implemented in two ways. Conventionally and dynamically. In a dynamic nature, content is loaded from an external server. However, the major problem with loading data from external servers/clouds is that it takes time to load content. In MAR applications, users must continuously position the camera towards the target until content is loaded to the screen. But, due to the delay in loading the target, users may not continuously position the camera toward the target and don't keep their attention towards the target, until processing the content. Hence, methods need to be introduced to keep the attention of the users. This research considered the methods to enhance the user experience while content is being loaded onto the mobile screen.

Under step 1 of this research, developed a prototype without any enhancements with three types of content (Text, Image, and Video) that needed to be loaded onto the screen using Unity Vuforia and Firebase technologies. The purpose of this is to compare the user experience when content size becomes greater. After that, a questionnaire survey was implemented using 20 participants to analyze the user experience, according to the results from the above questionnaire survey, an ANOVA test was performed to find out whether there was any difference in results mathematically. According to the results from One-way ANOVA Tests performed, both p values are less or equal to 0.05 for variables considered “Attention” and “Satisfaction”. This means there is a significant difference between the means of the results of the three content types concluding that user experience changes for different content sizes. Then, post-hoc Tests using Bonferroni correction were performed separately for variables Attention and Satisfaction to identify which content type (Text, Image, or Video) results are significantly different from others. Table 15 and Table 16, it is stating that T-tests performed for Text vs Video and Image vs Video have different user preferences. For both those comparisons, Video content type is constant. Hence, it can be concluded that the difference in the results lies in the results for Video content. But, if take the average of the values for variables Attention and Satisfaction into account, Video content has a lesser average (1 for less attention or satisfaction and 5 for higher attention or satisfaction) compared to other content types. Hence, a conclusion can be made that user preference for video content loading is significantly less than the other two content types compared to. Hence, it is stated that Enhancing methods need to be implemented to satisfy user experience and keep user interaction when loading larger content files.

Under step 2, with the help of a literature survey, five prototypes were developed using different types of enhancements with the target being to improve the user experience while video content is being loaded. Then, another questionnaire was performed with the same 20 participants to compare these five prototypes with the initial prototype with no enhancements. Then, an ANOVA test was performed to see whether there were any differences in the results from the users. According to the results from One-way ANOVA Tests performed, both p values are less or equal to 0.05. This means there is a significant difference between means of the results of user experiences in six prototypes. After that, post-hoc Tests using Bonferroni correction were performed separately for variables Attention and Satisfaction to identify which prototype user experience results are significantly different from others. Results from post-hoc Tests are shown in Table 20 and Table 21. According to the T-tests performed, the User experience of Prototype 1 has significantly different values compared to all other 5 prototypes. Also, according to the results from Table 17, it is visible that participants have answered prototype 1 negatively according to the two variables.

Hence, according to the above calculations, the conclusion can be stated that the user experience questionnaire shows participants show less attractiveness and satisfaction when video content loads dynamically without any enhancements (for prototype 1).

According to the user experiences, when content takes time to load to the screen, it is less likely to keep the user's attention in the application with Null Enhancements and it certainly can improve it by adding an enhancement method, especially a Hybrid method suggested here.

CHAPTER 6

FUTURE WORKS

Since this is being broad area of study, it is suggested to improve this research idea by conducting another research on Identifying content loading time based on content size and network bandwidth.

Then selecting the appropriate enhancement methods for different ranges of content loading times based on another questionnaire survey similar to this will help to improve more on this research topic.

Furthermore, this research is only considering two measurements "Attention" and "Satisfaction" to find the user experience on Mobile Augmented Reality Applications. Hence, studying the impacts to the user experience from Mobile Augmented Reality Applications based on different measurements needs to be considered.

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