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AUGMENTED REALITY MODEL WITH STORYTELLING ADAPTATION OF CULTURAL HERITAGE SITE

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DOCTOR OF PHILOSOPHY
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Abstrak

Tapak warisan budaya sering sukar menarik perhatian pengunjung moden ekoran persembahan yang statik dan kurang personalisasi. Tambahan pula, model Realiti Terimbuh (AR) sedia ada lazimnya bersifat umum dan kekurangan naratif adaptif untuk memenuhi keperluan individu. Tanpa integrasi elemen penceritaan, intervensi digital ini gagal menghasilkan kesan emosi, menyebabkan pengalaman melawat tapak warisan dilupai dan gagal meninggalkan kesan yang mendalam. Bagi menangani jurang tersebut, kajian ini memperkenalkan model Realiti Terimbuh Adaptif (AAR) yang diterapkan dengan elemen Penceritaan Digital (DST) untuk mewujudkan pengalaman budaya yang lebih mendalam dan bermakna. Penyelidikan ini bertujuan untuk memenuhi matlamat tersebut menerusi tiga objektif teras, iaitu: menganalisis komponen asas AAR, membina satu model konseptual yang menyeluruh, serta menilai fungsi prototaip dalam tapak warisan yang sebenar. Mengikut kerangka DSRM, penyelidikan ini dijalankan secara berfasa merangkumi lima fasa: kesedaran, cadangan, pembangunan, penilaian, dan kesimpulan. Model AAR yang merupakan hasil utama kajian ini dibentuk dengan menyatukan tiga elemen penting iaitu Persekitaran, Pemperibadian Pengguna, dan Komponen-komponen Lain. Seterusnya, model ini telah disahkan oleh panel pakar bagi memenuhi keperluan standard dalam meningkatkan penglibatan pengunjung di tapak warisan. Tambahan pula, prototaip aplikasi "The Mahsuri" dibangunkan untuk tapak Kota Mahsuri dengan ciri adaptasi kandungan mengikut demografi pengguna, khususnya naratif seni bina untuk dewasa, dan permainan pencarian harta karun bagi kanak-kanak. Keberkesanan aplikasi ini diuji secara intensif oleh 219 pengunjung menggunakan dua instrumen utama : *Handheld Augmented Reality Usability Scale* (HARUS) dan *Augmented Reality Immersion* (ARI), memastikan kebolehgunaan dan penglibatan pengguna. Hasil penilaian menunjukkan skor tinggi dalam aspek penglibatan, kebolehmanipulasian, dan kebolehfahaman, sekali gus memperkukuh dapatan bahawa kandungan yang diperibadikan mampu memberi kesan kepada pelbagai pengunjung. Meskipun kekangan persekitaran di tapak terbuka menjejaskan keterserapan mendalam, kajian ini merumuskan bahawa model AAR yang dicadangkan menyediakan penyelesaian yang mantap untuk mengintegrasikan fleksibiliti teknikal dengan penceritaan digital yang bermakna dalam konteks warisan budaya. Dari sudut teori, penyelidikan ini membina satu model asas bagi interpretasi warisan yang diperibadikan dengan menggabungkan teknologi adaptif bersama teori naratif. Secara praktikal pula, dapatan ini menyediakan model kepada pembangun untuk mereka bentuk pengalaman berpusatkan pengguna untuk aplikasi AAR dalam pemeliharaan dan mempromosi warisan budaya tidak ketara.

Kata Kunci: Realiti terimbuh mudah alih adaptif, Penceritaan digital, Keterlibatan pelawat, Pengalaman pengguna, Personalisasi

Abstract

Cultural heritage sites often struggle to engage modern visitors due to static presentations and a lack of personalization. Furthermore, existing Augmented Reality (AR) models tend to be one-size-fits-all, lacking the adaptive narrative elements required to create a personalized journey. Without an integrated storytelling element, these digital interventions fail to resonate emotionally, leaving the heritage experience forgettable and failing to make a deep impression. In addressing these gaps, this research introduces an Adaptive Augmented Reality (AAR) model infused with Digital Storytelling (DST) to create more resonant and meaningful cultural experiences. The study aims to achieve this through three key objectives: analysing the essential components of AAR, developing a comprehensive conceptual model, and testing prototype functionalities in a real heritage site. Following the Design Science Research Methodology (DSRM), this study was systematically executed across five phases: awareness, suggestion, development, evaluation, and conclusion. The study's primary output, the AAR Model, was developed by synthesizing three important elements: the Environment, User Personalization, and Other Components. This model was then validated by experts to ensure it met the necessary standards for enhancing visitor engagement at the heritage site. In addition, the study developed "The Mahsuri," a prototype for the Kota Mahsuri site that adapts its content based on user demographics specifically providing architectural narratives for adults, and treasure hunts for children. The application's effectiveness was rigorously assessed by 219 visitors through two primary instruments: the Handheld Augmented Reality Usability Scale (HARUS) and the Augmented Reality Immersion (ARI) metrics, ensuring both usability and user engagement. The evaluation yielded high scores for engagement, manipulability, and comprehensibility, affirming that personalized content resonates well with diverse visitors. Despite the environmental constraints of an outdoor site affecting deep immersion, the study concludes that the proposed AAR model provides a robust solution for integrating technical flexibility with meaningful digital storytelling in cultural heritage contexts. Theoretically, this research establishes a foundational model for personalized heritage interpretation by merging adaptive technology with narrative theory. Practically, this finding provides a model for developers to design user-centric experiences for AAR application in preserving and promoting intangible cultural heritage.

Keywords: Mobile adaptive augmented reality, Digital storytelling, Visitor engagement, User experience, Personalization

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List of Abbreviations

AR	Augmented Reality
AAR	Adaptive augmented reality
A^2R	Adaptive augmented reality
UX	User Experience
HMD	Head Mounted Display
VR	Virtual Reality
IoT	Internet of Things
AltR	Alternative Reality narrative
VISAS	Virtual and augmented exploitation of Submerged Archaeological Site
POI	Point of Interest
DST	Digital Storytelling
EV	Environment
UP	User Personalization
OC	Other Components

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CHAPTER ONE
INTRODUCTION

1.1 Overview of The Study

Augmented Reality (AR) has recently been integrated into various fields and applications (Keil et al., 2013; Kipper & Rampolla, 2012). This technology enables users to view the real world while interacting with computer-generated content (Vera & Sánchez, 2016; Yuan et al., 2018), through devices such as smartphones, tablets, head-mounted displays, or smart glasses. Nowadays, the advancement of AR technology has also expanded to mobile and wearable Internet applications.

Recent studies have explored the influential factors in AR applications, highlighting the importance of user experience and technological integration. Nguyen et al. (2023) conducted a systematic review that sheds light on current trends and explores future directions in AR technology.

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The educational sector has also benefited from AR advancements, Koumpouros (2024) highlights the potential of AR in education, emphasizing its ability to provide immersive learning experiences that significantly boost student engagement and deepen understanding. Furthermore, the development of mobile AR applications has enabled innovative uses across domains such as gaming, healthcare, and navigation. The integration of AR with mobile and wearable devices has facilitated real-time information overlay, improving user interaction and experience (Davari, 2022). These advancements underscore the growing significance of AR technology in enhancing user interaction with digital content across multiple platforms and devices.

In the tourism industry, AR has become a transformative tool in enhancing visitor experiences and providing innovative ways to engage with destinations. Recent studies have explored various applications and impacts of AR in tourism. AR applications could enrich tourists' understanding and interaction with cultural and natural heritage sites (Ariza-Colpas et al., 2023), facilitate virtual tours and experiences, allowing continued engagement with destinations during travel restrictions (Ariza-Colpas et al., 2023), enhance usability and overall tourist experience (Williams et al., 2020), and promote cultural heritage and support sustainable tourism practices (Zandi, 2023). These studies highlight the diverse role of AR in modern tourism, enhancing visitor experiences while also addressing challenges in the post-pandemic era. As AR technology evolves, its integration into tourism is anticipated to grow, opening up new opportunities for engagement and education.

Adaptive Augmented Reality (AAR) is an advanced form of augmented reality that responds to and adapts to real-time context and user characteristics. (Damala & Stojanovic, 2012; Tenemaza et al., 2015). AAR is designed to enhance user engagement by adapting 3D augmented reality content to suit individual needs and preferences better (Tenemaza et al., 2016).

AAR is an evolving concept in augmented reality that dynamically adjusts to real-time contexts and user-specific characteristics, enhancing user engagement and interaction. Recent research has further explored and expanded upon this concept. For example, Davari (2022) proposed a framework for designing intelligent AR interfaces that infer user needs and adapt accordingly, enhancing the relevance and effectiveness of AR content. Evangelista Belo et al. (2022) proposed the Adaptive User Interfaces Toolkit

(AUIT), a versatile toolkit designed to streamline the adaptation of virtual elements to users' contexts. It enables integrating multiple adaptation objectives while unifying previous research for practical implementation. While Yigitbas et al. (2020) identified architectural patterns essential for developing context-aware AR applications, addressing challenges such as multi-platform capability and real-time adaptation to user contexts. These studies contribute to the advancement of AAR by focusing on intelligent interface design, toolkit development for adaptive user interfaces, and the integration of context-aware systems to improve user engagement and situational awareness.

Personalization and emotion are key elements of effective storytelling. Incorporating emotion into digital stories helps to captivate audiences and immerse them more deeply in the storytelling experience (Lambert, 2006; Ohler, 2008; Tenh, 2013). The inclusion of digital storytelling in AR technology seems to be the right combination for presenting cultural heritage information and improving the user experience. Studies show that storytelling has proven to be a powerful tool for engaging users and inspiring them to explore and learn more about cultural heritage. By weaving narratives into the presentation of heritage, it creates an emotional connection that fosters curiosity and a deeper understanding (Dusi et al., 2017; Fenu & Pittarello, 2018; Rizvic, 2015; Rubino et al., 2015; Wang, 2018). The use of digital storytelling with Augmented AR technology in museums has been shown to effectively engage and inspire individuals to learn more about cultural heritage by immersing them in exhibitions or artifacts through emotional engagement (Chan et al., 2019).

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Digital storytelling in Augmented Reality (AR) merges traditional narrative techniques with interactive digital elements, creating immersive experiences that engage users in novel ways. Recent advancements have expanded the applications and understanding of AR in digital storytelling. These developments illustrate the expanding role of AR in digital storytelling, offering innovative methods to engage audiences across various domains, including education (*Augmented Reality Storytelling: An Innovative Worldbuilding*, 2024), journalism (Drisya, 2024), and personal narratives (Asquith & Frazier, 2022).

However, the adoption of AR or AAR technology in Malaysia remains relatively low compared to other countries (Saidin et al., 2015). This outstanding technology has been applied in various fields, including heritage. According to Pendit, Shiratuddin and Zaibon (2012)AR is one of the most reliable ways to conserve monuments and preserve history. Usually, signage is used to provide information. However, AR could provide effective ways to experience the stories by "living through" the story digitally (Bimber et al., 2003). AR technology can collaborate with digital storytelling to assist cultural heritage in accessibility issues and provide information to the users through narrative (Kasemsarn & Nickpour, 2015). This research highlights the potential of combining Augmented Reality technology with digital storytelling to enhance the presentation and engagement of cultural heritage information.

AR can virtually reconstruct ruin artefacts (Kolivand et al., 2019) and stimulate learning engagement (Challenor & Ma, 2019). While having the same capability, AAR is able to enhance the visiting experience at museums or heritage sites by providing the content based on the user's interests (Damala et al., 2013). The presentation and

narration of the exhibitions will be digital and user-centric. It may help address constraints faced by museums and galleries, such as limited resources, limited access, and limited exhibition space.

Heritage is the unique identity and rich history of a nation that must be diligently preserved to serve as an invaluable lesson for future generations. Over time, technology has played an increasingly pivotal role as a mediator in museums and cultural heritage sites. This ranges from the development of informative websites and engaging multimedia presentations to the exciting emergence of innovative technologies like Augmented Reality, which have demonstrated incredibly promising results in enhancing visitor experiences and preserving historical assets for posterity (Pendit et al., 2014).

Digital heritage involves the use of digital technologies to preserve, document, and present cultural heritage, encompassing both tangible and intangible elements. AR has become a pivotal tool in this field, offering innovative methods to engage audiences and enhance the accessibility of cultural assets. Boboc et al. (2022)suggests that AR enables users to interact with and explore items in a virtual space, thereby enriching their understanding and fostering greater appreciation. AR introduces interactive and engaging methods for learning about cultural heritage (Boboc et al., 2022); and AR can effectively communicate intangible cultural heritage, such as traditional craftsmanship and practices, by overlaying digital information onto physical environments, thereby enriching the storytelling experience (Salman, 2023). These studies highlight the significant role of AR in preserving and promoting digital heritage, offering dynamic, interactive ways to experience and engage with cultural assets.

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1.2 Problem Statement

Augmented Reality (AR) technology and narrative have proven valuable for safeguarding cultural heritage. It is important that these technologies are implemented within a framework that offers an interactive medium for engaging with historical events. While traditional signage has been the primary method of conveying information and stories, AR now enables visitors to immerse themselves more effectively in the narratives by digitally "experiencing" the story (Bimber et al., 2003).

Current cultural heritage interpretation often fails to fully engage visitors, largely due to the static nature of exhibits and their inability to contextualise fragmented historical remains within their original settings (Anay et al., 2023). This deficiency creates a disconnect between artifacts and their intangible cultural heritage, impeding a deeper understanding and appreciation among visitors. (Galani & Vosinakis, 2024). This limitation frequently results in a diminished educational experience and a failure to convey the rich narratives embedded within these historical contexts (Dima, 2022). Consequently, there is a pressing need for innovative technological solutions that can bridge this gap by providing immersive and interactive experiences, thereby enhancing visitor engagement and fostering a more profound connection to both tangible and intangible cultural heritage (Galani & Vosinakis, 2024).

Despite recent advancements in AR for cultural heritage, existing frameworks primarily focus on technical implementation, event sequencing, or user interaction mechanics (Chatsiopoulou & Michailidis, 2023; Nikolarakis & Koutsabasis, 2024)(Chatsiopoulou & Michailidis, 2023; Nikolarakis & Koutsabasis, 2024). Frameworks such as MAR-ED (Kim & Woo, 2025) and Object Driven Narrative (Sun

et al., 2025) offer adaptive narrative features or AI-driven content personalization but do not empirically evaluate their impact on visitors' emotional engagement or narrative comprehension. Gamified AR architectures (Martusciello et al., 2025) and mobile AR design patterns (Nikolarakis & Koutsabasis, 2024) provide system-level personalization and interaction guidance, yet they lack a structured adaptive narrative. Collectively, these studies highlight that there is currently no comprehensive, empirically validated framework that integrates adaptive storytelling with both engagement and narrative clarity for cultural heritage experiences.

The focus should be on personalization, adaptation, and delivering interpretation and learning materials that best fit the visitors' needs (Sookhanaphibarn & Thawonmas, 2009). However, these elements are currently missing in Malaysia's local setting (Li et al., 2023; Shang et al., 2017). Therefore, the integration of AR in Malaysian museum exhibitions through mobile applications has the potential to address these gaps and provide a more personalized and engaging experience.

A more efficient way to gain this experience is by using Adaptive Augmented Reality (AAR). AAR delivers information to users by leveraging interaction tracking and device sensors. AAR is an augmented reality application that tailors real-time information to the user's unique characteristics, interests, and context. Meeting users' needs is essential for enhancing their interaction experience, and this is now possible through emerging mobile phone technologies. Some of the issues that have been identified with AAR include the need for a formal model to enable adaptation to local context and environment (Tenemaza et al., 2015), as well as the absence of established development guidelines and best practices (Damala & Stojanovic, 2012; Johnson et al.,

2011). Moreover, incorporating storytelling to enrich the user's experience in such augmented reality environments is seldom addressed (Dal Falco & Vassos, 2017), and to ensure that story events align contextually with physical spaces (Li et al., 2023).

The primary objective of this research is to propose an AAR model that encompasses user, context, interaction, engagement, and environment models for implementation at a cultural heritage site as a proof of concept. This initiative is driven by a clearly defined research question and specific objectives.

1.3 Research Questions

The identified limitations in current cultural heritage and AR storytelling highlight a critical need for improved narrative design to foster deeper engagement and enhanced comprehension. Therefore, to achieve the aim discussed above, the following research questions have been formed:

i. What are the core components that define the adaptive augmented reality (AAR) conceptual model for cultural heritage sites?
ii. How the components identified suit into AAR model for the cultural heritage site?
iii. How usable is the AAR prototype for cultural heritage site which developed based on the proposed AAR model?

1.4 Research Objectives

To address the research questions, this study establishes objectives to define the AAR model, synthesise its core components, and evaluate its usability. These objectives

guided the model's development and the creation of a prototype, ensuring effective application in fostering meaningful cultural heritage storytelling.

i. To analyse the core components of Adaptive Augmented Reality (AAR) for a cultural heritage site.
ii. To propose AAR conceptual model for cultural heritage site.
iii. To evaluate the usability of the AAR prototype, created as a proof of concept based on the proposed AAR model.

1.5 Theoretical and Research Framework

This study is based on theories and concepts related to augmented reality, storytelling, user experience and acceptance at the heritage site. The research framework is discussed based on the five phases of the design research methodology (Vaishnavi & Kuechler, 2008; Vom Brocke et al., 2020), which are: awareness of problem, suggestion, development, evaluation and conclusion. The first phase (awareness of the problem) reviewed the concepts and models of AR and storytelling to identify the existing models, the research gap, and the research focus. In the second phase (propose solution), theories and existing models or frameworks of AR and storytelling were reviewed to define the components of the AAR conceptual model developed in the third phase (development). In the fourth phase (evaluation), the expert validated the initial conceptual model, and improvements were made based on the expert's suggestions. The prototype was then developed based on the improved and final conceptual model. The prototype was evaluated based on the usability of AAR at a heritage site. The survey results defined the usability of AAR at the heritage site. Lastly,

in the conclusion phase, the findings of the study were reported. The research framework is depicted in Figure 1.1.

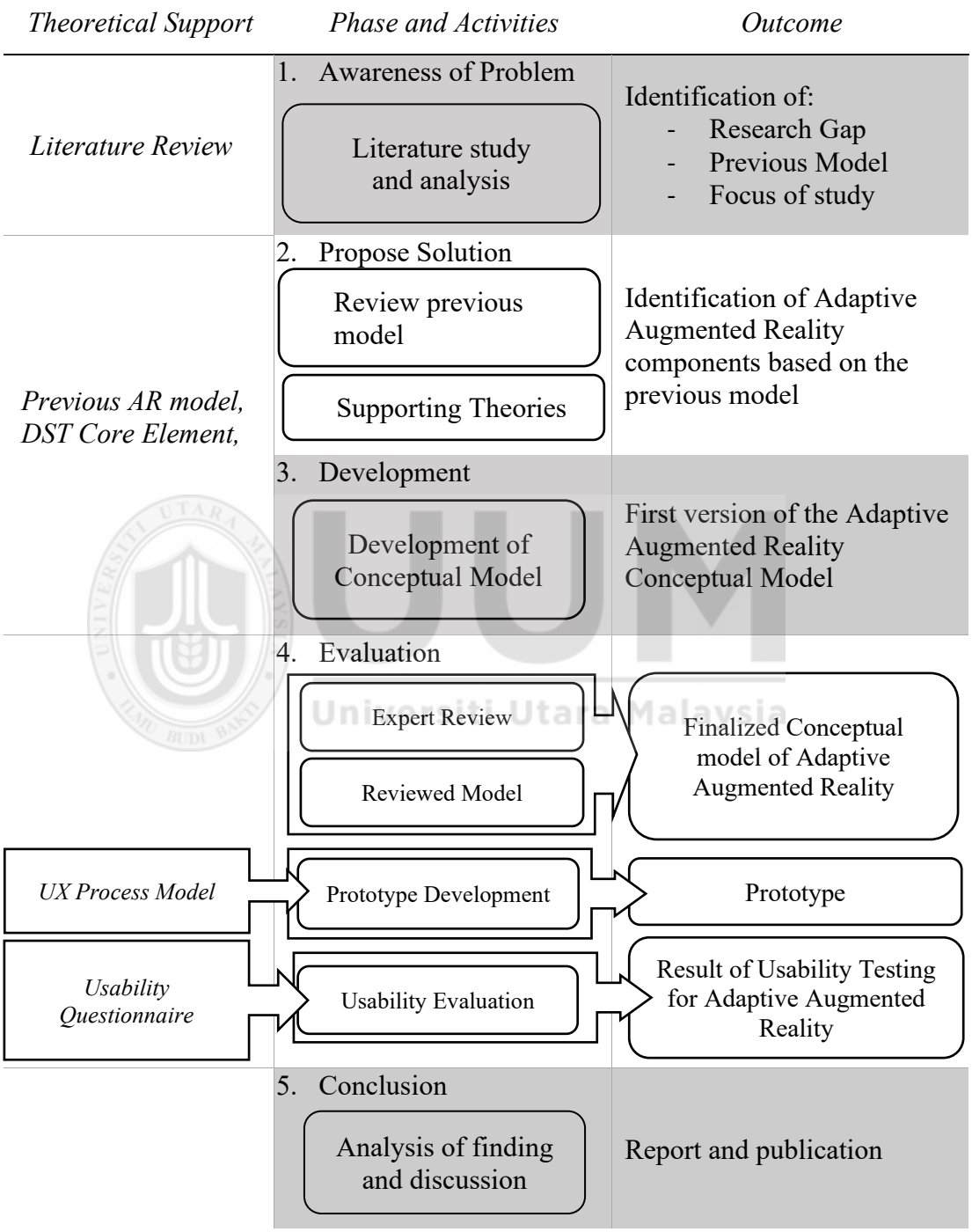


Figure 1.1. Theoretical and Research Framework

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1.6 Research Scope

This study focuses on the development of an adaptive augmented reality model for cultural heritage within these scopes:

a. This study focuses on the use of mobile Augmented Reality (AR) and adaptive storytelling technologies to enhance the visitor experience at heritage sites, Kota Mahsuri at Langkawi, Malaysia.

b. The Mahsuri AAR prototype is an Augmented Reality (AR) mobile app developed for Kota Mahsuri at Langkawi, Malaysia. The app incorporates the tale of Mahsuri as well as elements of the culture, architecture, and history of Langkawi.

c. Evaluation by potential stakeholders. Evaluation was conducted with potential stakeholders. The sample selected for user evaluation consisted of visitors to Kota Mahsuri at Langkawi, Malaysia, who are considered as the primary potential stakeholders for the AAR user.

1.7 Contributions of the Study

The contributions of this study are multifaceted and can be categorized into three main areas: theoretical, practical, and functional. Each category reflects the unique value and impact that this research aims to bring to the field of AAR and its applications. These contributions are elaborated as follows.

i. Theoretical Contributions

The main contribution of this study is the conceptual model of AAR for cultural heritage. It has considered the component of the AR concept, storytelling elements, and user experience. As there are limited models depicted to achieve that, the theoretical framework is also a fruitful contribution since literature, previous models, and theories help shape the research gap and formulate the conceptual model. Furthermore, it also shows the evaluation process to verify the conceptual model. This model contributes to the body of knowledge in the Multimedia and Human-Computer Interaction Field.

ii. Practical Contribution

The proposed conceptual model is the practical contribution. It served as a guideline in developing an AR application for the heritage site to create awareness of the importance of heritage and history. Since it was evaluated by users through usability studies, the results indicated whether the concept could be applied in the heritage field.

iii. Functional Contribution

The AAR prototype developed based on the proposed conceptual model represents the functional contribution of this study. The prototype incorporates the tale of Mahsuri alongside cultural, architectural, and historical elements of Langkawi. With the contents that adapt to the user's age category (adult or child), the prototype delivers a personalised experience. Whether through digital storytelling, games, or digital object illustrations and explanations, the prototype provides a novel and engaging approach to interactive content delivery.

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1.8 Significance of the Study

The findings of this research are anticipated to yield significant theoretical, methodological, and practical implications across the fields of Human-Computer Interaction (HCI), Cultural Heritage, and Educational Technology.

Enhancement of Cultural Heritage Preservation and Dissemination: This study provides a validated framework for applying Augmented Reality (AR) and digital storytelling to cultural heritage sites, thereby offering a sustainable, engaging alternative to traditional interpretive methods. The final model addresses the global challenge of making heritage sites relevant and accessible to younger, digitally native audiences, potentially increasing tourist engagement and knowledge retention.

Theoretical Advancement of Adaptive AR (AAR): The research contributes to AR theory by empirically validating a novel conceptual model that integrates storytelling adaptation principles (e.g., age-based content modulation) with core AR technology design. This moves the field beyond descriptive AR application studies by formally establishing the relationship between adaptive user profiling and positive user experience metrics.

Methodological Utility for Practitioners: The research delivers an empirically validated, multi-item instrument designed specifically to measure user experience (UX) within the context of storytelling-based AR heritage applications. This instrument will serve as a reliable, ready-to-use methodological tool for designers, museums, and educators seeking to assess the effectiveness and usability of their own immersive learning technologies.

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Support for Educational Tourism Policy: By demonstrating the measurable improvement in user comprehensibility and engagement achieved through the adaptive storytelling model, this research offers evidence-based recommendations for tourism boards and local governments on investing in and deploying technology to enhance the educational value of historical sites.

1.9 Operational Definition and Terminologies

The following definitions clarify the key terms used throughout this study to ensure consistency and a shared understanding of the concepts central to the research:

i. Augmented Reality (AR)

AR is defined as a technology that integrates digital content, such as graphics, text, and audio, into real-world environments in real-time, enhancing the user's perception of reality. This research AR is emphasizing on the blending of digital and physical worlds to improve interactivity and user experience.

ii. Adaptive Augmented Reality (AAR)

AAR is an augmented reality application that responds to the user's unique characteristics, interests, and context with useful and effective real-time information. The users become more immersed in the exhibition based on their personal emotional experience.

iii. AAR Conceptual Model

A representation of a concept that consists of AR technology, digital storytelling's elements, and cultural heritage site. It can be a guidance for the development of mobile AR application with storytelling adaptation in the heritage field.

iv. Cultural Heritage

Heritage is the tangible and intangible legacy that is inherited from the past. The United Nations Educational, Scientific and Cultural Organization (UNESCO) categorised the tangible cultural heritage as: "movable cultural heritage (paintings,

sculptures, coins, manuscripts), immovable cultural heritage (monuments, archaeological sites, and so on) and underwater cultural heritage (shipwrecks, underwater ruins and cities)"; while the intangible cultural heritage: oral traditions, performing arts, rituals (UNESCO, 2017). The scope of this study was more likely covering the tangible cultural heritage as defined by UNESCO.

v. Digital Storytelling

Storytelling was regarded as an art of narrating stories to convey messages from one party to another. In the context of this study, however, the focus was placed on its digital form. Accordingly, the definition was more closely aligned with digital storytelling, which referred to the practice of conveying narratives through digital media, including photographs, audio, video, and three-dimensional objects.

vi. User Personalization (UP)

User Personalization (UP) is defined as the component that utilizes user information (e.g., profiles, locations, and real-time conditions) to enable adaptivity and optimize the interaction experience. UP's core function is sensing user data (such as age, gender, height, etc.) to ensure the system adapts its content to individual needs and preferences. This component leverages available sensors to gather the necessary data for adapting the experience.

vii. Environment (EV)

The Environment (EV) component refers to the elements that define and shape the interaction environment, including the medium, media, and context of content delivery. EV supports comprehension through its visual presentation, spatial layout, and contextual cues.

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viii. Other Components (OC)

Other Components (OC) represent the necessary framework of devices, technologies, and services that facilitate and support interactions within the AAR environment. This component is crucial for enabling smooth functionality and enhancing the system's overall adaptability.

1.10 Structure of the Thesis

The structure of this report is carefully organized to guide the reader through the various components of the study, as outlined below:

Chapter 1: This chapter provides a comprehensive introduction to the research. It begins with the background of the study, highlighting the context and significance of the research area. This is followed by a discussion of the problem background, identifying the research gap that this study aims to address. The chapter also presents the research questions and objectives, outlines the theoretical and research framework, defines the scope of the study, and elaborates on the contributions of the research. Finally, it includes operational definitions and key terminologies to ensure clarity and consistency throughout the report.

Chapter 2: This chapter delves into the review of literature related to the study. It explores key topics such as Augmented Reality, Adaptive Augmented Reality, storytelling in heritage, relevant theories, and models. The review begins with broader issues and gradually narrows its focus, converging on the specific research gap this study seeks to fill. This chapter establishes the theoretical foundation for the research and identifies areas that require further investigation.

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Chapter 3: This chapter provides a detailed explanation of the methodology employed in conducting the study. It adopts the Design Research Methodology proposed by Vaishnavi and Kuechler (2007) to systematically achieve the research objectives. The methodology is structured into five main stages: awareness of the problem, suggestion, development, evaluation, and conclusion. Each stage is discussed in depth, outlining the approach and techniques used to ensure the rigor and validity of the research process.

Chapter 4: This chapter focuses on developing a conceptual model for Adaptive Augmented Reality (AAR) applications in heritage sites. By analyzing previous frameworks, the chapter identifies three core components of AAR: Environment (EV), User Personalization (UP), and Other Components (OC). The EV encompasses media, interaction, and context to adapt content presentation, while UP personalizes experiences based on user characteristics such as age and physiological traits. OC refers to devices, sensors, and services that support AAR functionalities. The chapter also integrates principles of digital storytelling, emphasizing elements like dramatic questions and user contributions to enrich narratives. Additionally, a user-centered UX design process is proposed, outlining steps from understanding user needs to designing and testing the application.

Chapter 5: This chapter presents the evaluation of the AAR application conducted at Kota Mahsuri, Langkawi. The usability study involved 219 participants who tested the application and provided feedback on its comprehensibility, manipulability, engagement, engrossment, and immersion. The findings reveal strong user satisfaction, particularly in engagement and usability dimensions, highlighting the application's

novelty and ease of use. However, ergonomic challenges, such as arm fatigue, and moderate ratings for engrossment and total immersion suggest the need for design refinements. The results underscore the potential of the application as an innovative tool for heritage exploration while identifying areas for improvement, such as enhancing interaction design and narrative depth.

Chapter 6: This chapter concludes the study by reflecting on its objectives and contributions. The research successfully developed a conceptual model for AAR applications tailored to heritage sites, integrating digital storytelling and UX design principles. Key contributions include the structured approach to designing adaptive and user-centric applications and validating the model through practical implementation. Despite its achievements, the study acknowledges limitations, such as testing constraints during the COVID-19 pandemic, limited storytelling activities, and the generic nature of the conceptual model. These limitations provide avenues for future research to enhance model specificity, expand content diversity, and conduct broader evaluations. Overall, the chapter emphasizes the potential of AAR to transform heritage experiences while laying the groundwork for further innovation.

1.11 Summary

The chapter provides an in-depth overview of the research, including the problem statement, detailed research questions, specific objectives, a comprehensive theoretical and research framework, scope of the study with clear boundaries, and anticipated contributions. Additionally, it describes meticulous methods to achieve each objective and outlines expected outcomes. Further discussion on relevant literature is found in the next chapter

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter discusses the literature regarding augmented reality (AR), adaptive augmented reality (AAR), storytelling in heritage, and other related models such as the existing AR model, the User Experience (UX) design process model and the AR acceptance model. This chapter focuses on reviewing existing conceptual models of Augmented Reality (AR) and the Adaptive Augmented Reality (AAR) conceptual model. The proposed AAR model integrates storytelling elements specifically designed to enhance the experience of heritage sites.

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2.2 Augmented Reality

Augmented Reality (AR) provides an overlay of virtual content (text, audio, video, 3D objects) on a real-world view through a monitor, mobile phone, or head-mounted display without replacing the real environment (Azuma et al., 2001; Milgram et al., 1994). Milgram et al. (1994) identified AR as a subclass of mixed reality, as defined by Azuma et al. (2001), with three characteristics: (i) real and virtual objects merged in a real environment, (ii) Interactive and real-time, (iii) Alignment of the virtual and real objects. By agreeing on the definition, Hollerer and Feiner (2004) also define an AR system as "one that combines real and computer-generated information in a real environment, interactively and in real-time, and that aligns virtual objects with physical ones." On the other hand, the definition is given by Dudzik (2018), AR is "an interactive, real-time direct or indirect view of a physical environment that has been

enhanced by the superimposing of computer-generated sensory information, such as images, sounds, videos, and haptics. (p.1)" These definitions have pointed AR to some similar key terms, such as interactive, real-time, and integrating with virtual content to enhance the real environment.

In the early days, AR was bulky as a 'see-through' Head Mounted Display (HMD) had to be attached to a desktop computer or a laptop to operate (Milgram et al., 1994). With the advancement in technology, the size of the AR device became smaller and more mobile, such as mobile phones and Google Glass. AR had been introduced in military and aviation manufacturing long before it became available to the public user. Due to the advancement in mobile technology, AR has been applied in various fields such as marketing, education, medical, manufacturing, entertainment, tourism and others (Mekni & Lemieux, 2014). Museums and heritage are another field taking advantage of this edge cutting technology, for example, "Svevo Tour" is an AR project to promote the famous Italian novelist, *Italo Svevo* (Fenu & Pittarello, 2018). AR is again taking a leap when "Adaptive" has been encapsulated in this technology. Adaptive Augmented Reality (AAR) will be further discussed next.

2.3 Adaptive Augmented Reality (AAR)

Adaptive Augmented Reality (AAR) represents an advanced evolution of augmented reality, designed to dynamically adjust content and interactions based on real-time contexts and user-specific characteristics (Damala et al., 2012; Tenemaza et al., 2015). By enabling the adaptation of 3D augmented reality content, AAR enhances user engagement and interaction. For example, in a museum setting, AAR can immerse

visitors in exhibitions or artifacts by tailoring the experience to their emotional states (Damala et al., 2013).

There had been a few studies exploring AAR applications across various fields, including cultural heritage, support for individuals with disabilities, and assistance for the elderly. One notable study investigated AAR's use in helping individuals with mild intellectual disabilities in Ecuador (Tenemaza et al., 2016). This research focused on developing an application to assist patients in finding their way home when lost, while simultaneously notifying their caretakers. This innovative solution benefits both patients and caregivers and builds on the researchers' earlier work (Tenemaza et al., 2015).

In another example, AAR has been applied to assist elderly individuals living alone with daily chores (Hervás et al., 2013). Additionally, Damala et al. (2012) explored the use of AAR in creating an augmented reality guide for museum visits. Their research aimed to enhance the presentation of information to visitors by adapting content based on their psychological states. They introduced a concept called Adaptive Augmented Reality (A2R), which utilized physiological sensors to monitor visitor interest. Based on these insights, multimedia content was dynamically adjusted and delivered through a see-through AR display, enabling interaction via gestures. This approach marked a significant breakthrough for applying AAR in the heritage field.

Magalhaes et al. (2014) proposed an architecture and information system for an adaptive mixed-reality system. Their work focused on seamlessly visualizing virtual reconstructions of archaeological sites integrated with real-world scenes. They introduced a novel adaptive methodology that blends real and virtual environments,

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advancing the application of AR techniques for heritage visualization. However, their approach relied solely on existing in-situ visualization, limiting visitors' ability to experience consistent and immersive visuals across different contexts.

Deliyannis and Papadopoulou (2016) explored the development of innovative user experiences in museums and cultural heritage settings. Their work emphasized specific design features that enable the seamless integration of content presentation, interactive exploration, and the incorporation of game modes. This approach leverages open and expandable unified information domains to enhance user engagement. Dal Falco and Vassos (2017) explored innovative methodologies combining Interaction Design, Interactive Storytelling, and Artificial Intelligence to revolutionize cultural heritage experiences. They proposed a groundbreaking paradigm for museum experience design that seamlessly blends traditional visual and multimedia communication with immersive storytelling. This approach reimagines interactions with artifacts, transforming them into dynamic and engaging narrative experiences. Recognizing the evolving role of museums, the researchers highlighted the growing emphasis on integrating digital information with physical artifacts. This integration aims to enhance cultural accessibility and enrich visitor engagement, bridging the gap between tangible heritage and contemporary digital technologies.

While these studies on Adaptive Augmented Reality (AAR) have proven valuable in their respective fields, a formalized definition that incorporates local context, user interaction, and environment models to guide the development of such assistive technologies has not yet been established (Mompeu et al., 2024; Tenemaza et al., 2015). Looking at all the advancements and changes that are happening in the heritage field

abroad and noticing that in Malaysia, there is still a major gap and lack of development in this area, it is time that a study should be proposed to lessen this gap in the local context.

2.4 Adaptive Augmented Reality Models

This section aims to examine four foundational models to identify the core components of Adaptive Augmented Reality (AAR). The first model, developed as part of the ARtSENSE project by Damala et al. (2012)It introduces an Adaptive Augmented Reality (A^2R) framework that emphasizes personalized interactions within AR environments. The second, Hervás et al. (2013) contribute with their Context-awareness Adaptive AR Model (i-ARA), which dynamically adjusts AR content based on real-time contextual factors. Tenemaza et al. (2015) present an A^2R framework built around three key models: the User Model, the Context Model, and the Interaction Model, each essential for adaptive AR systems. Last but not least, Abidin et al. (2017), focuses on an Adaptive Multimodal Interaction framework for mobile AR, which enhances user experiences through flexible interaction methods. By analyzing these models, this section seeks to identify the fundamental components that underpin effective AAR systems.

2.4.1 ARtSENSE - Adaptive Augmented Reality (A^2R) model

The ARtSENSE project by Damala et al. (2012) explores the concept of adaptive augmented reality (A^2R) to enhance visitor experiences in cultural heritage institutions like museums. The system integrates multiple sensory inputs, including visual, acoustic, and psychophysiological sensors, to track visitors' engagement with exhibits. The digital content is dynamically adjusted in real-time, offering a personalized

experience based on individual interests and responses. For example, if a visitor shows heightened interest in a specific exhibit, the system provides more detailed information, whereas disengagement prompts the suggestion of alternative content or exhibits. The core innovation lies in the feedback loop that assesses a visitor's psychological and physiological state to modify the augmented reality content. Through Head-Mounted Displays (HMDs) and biosensors, the system monitors aspects like gaze direction, heart rate, and environmental noise to deliver tailored digital media. The goal is to make museum visits more immersive and interactive, adapting to each visitor's needs based on their real-time responses. This technology aims to bridge the gap between digital media and physical exhibits, enhancing learning and engagement.

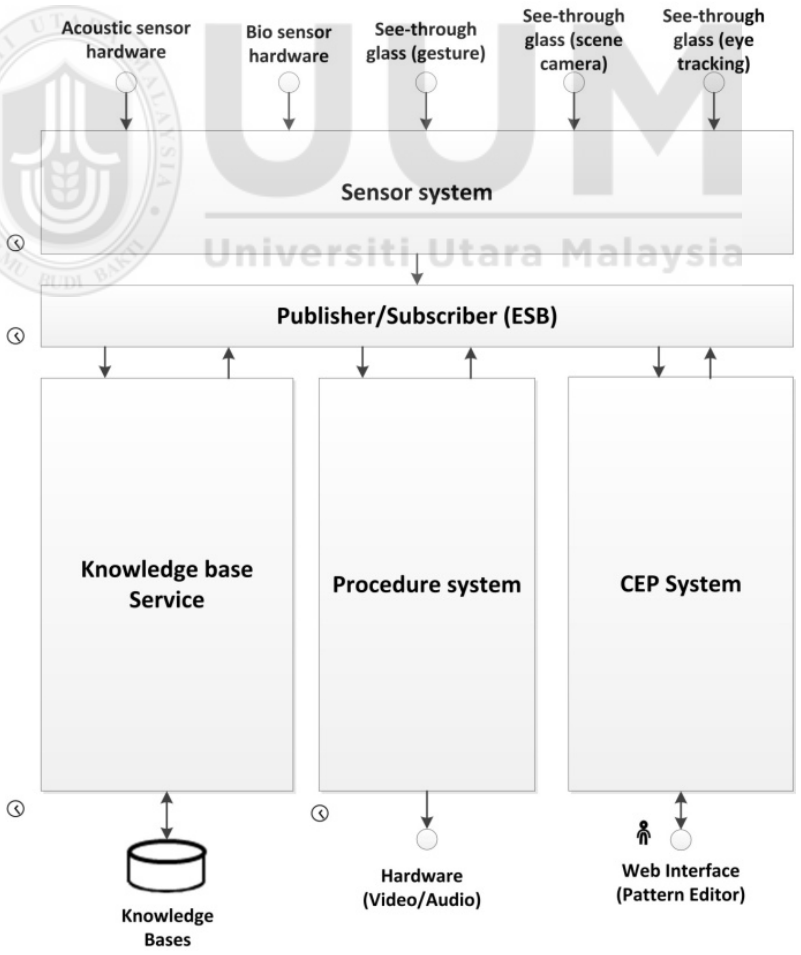


Figure 2.1. ARtSENSE Adaptive Augmented Reality Architecture

The A^2R system is implemented across various museum types, each offering distinct experiences, collections, and visitor profiles. For instance, a visitor viewing a particular artwork might be provided with historical and contextual details aligned with their level of interest and background. If the visitor appears disinterested, the system could shift to a more engaging narrative style or suggest alternative content. Over time, this feedback helps curators understand visitor interests and boredom, offering insights to shape future exhibits.

The A^2R approach can transform how cultural institutions engage with the public, offering more individualized learning opportunities and increasing the overall appeal of museums by providing a richer, more interactive experience. This represents a significant advancement in using augmented reality for educational purposes, especially in settings that require balancing diverse visitor interests and engagement levels.

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2.4.2 Adaptive Augmented Reality (A^2R) Model

Tenemaza et al. (2015) proposed a sophisticated framework of interconnected models to underpin the development of effective A^2R systems. This framework revolves around three key models: the User Model, the Context Model, and the Interaction Model.

The core of this framework is the User Model, which aims to capture a comprehensive representation of the individual using the A^2R system. It builds upon traditional user models by incorporating not only standard demographic and cognitive factors, such as age, language proficiency, and prior knowledge, but also crucial physical and

physiological data. This includes the user's location, posture, movement patterns, and even physiological responses like heart rate and gaze direction. By considering these real-time physical and physiological cues, the A^{2}R system can tailor its output to the user's immediate physical state and surroundings. Complementing the User Model is the Context Model, which reflects the user's current situation and environment.

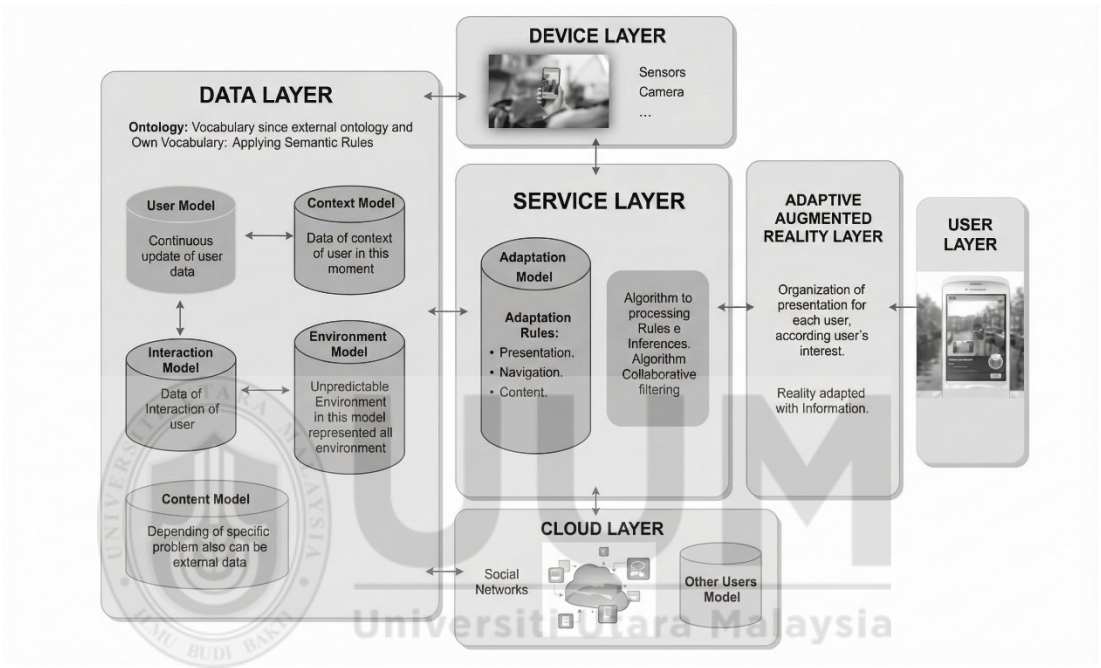


Figure 2.2. Adaptive Augmented Reality Architecture

The Context Model encompasses three key elements: the physical environment, the social context, and the user's current task and objective. The physical environment considers factors like lighting, noise, and nearby objects that may impact the user's experience. The social context accounts for the presence of others, their relationship to the user, and social norms, allowing the A^{2}R system to adapt accordingly. Understanding the user's current task and goal within the A^{2}R application is essential for providing relevant and timely assistance. The third component is the Interaction Mode, which serves as a detailed record of the ongoing interaction between the user

and the A^2R system. It meticulously records both user actions, such as navigational choices, selections made, and data input, as well as system responses, including content displayed, feedback provided, and adaptations made based on user behavior or context. This chronological record of interactions enables the system to learn from past interactions and adapt its behavior to better suit the user's evolving needs and preferences.

The three models work together dynamically. The AAR system continuously updates the models as the user interacts with it. This information is then used by an "Adaptation Engine" to adjust the AAR experience in real-time. The interplay of models allows the AAR system to learn and adapt to the user's needs and preferences, creating a more personalized and effective experience. This approach is crucial for making AAR more intuitive and responsive, improving user experience in applications ranging from tourism to personalized learning environments.

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2.4.3 Ontological Context-Awareness for Adaptive AR Model

Hervás et al. (2013) presents a framework for enhancing augmented reality systems by integrating context-awareness and personalization through the utilization of ontologies and Semantic Web principles. The proposed system, referred to as i-ARA, supports adaptive behavior by comprehending the user's environment and needs, enabling the delivery of relevant information based on their interactions with real-world objects. By leveraging mobile devices, the system establishes connections between physical objects and digital information through technologies such as QR codes and NFC, thus making the AR experience more intuitive and responsive.

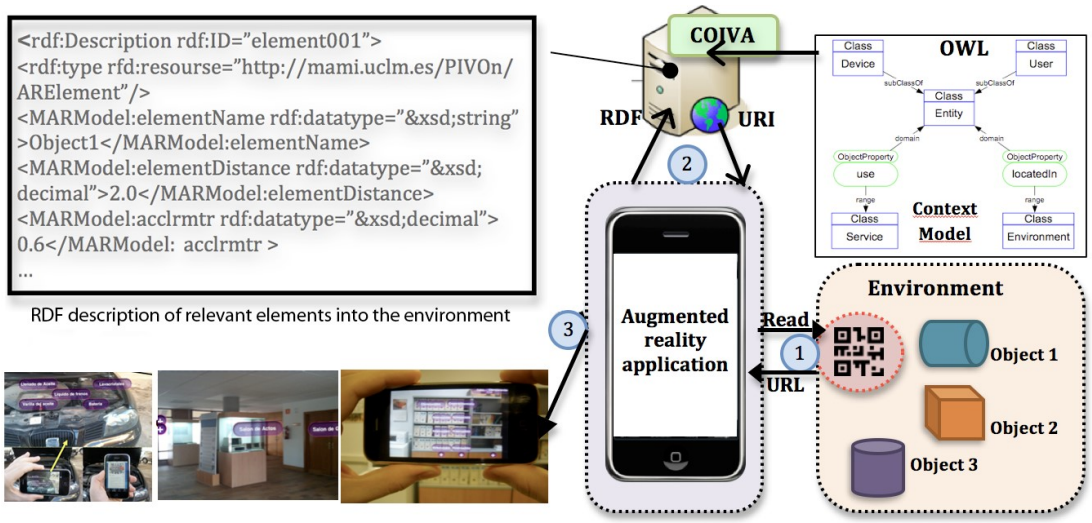


Figure 2.3. i-ARA Architecture

The core innovation of this work lies in the employment of context models that describe users, devices, the environment, and services. These models empower the system to reason about the user's situation and dynamically adjust the AR content accordingly. Algorithms and reasoning techniques, including the Web Ontology Language (OWL) and the Semantic Web Rule Language (SWRL) rules, are utilized to infer user needs and strategically position relevant information within the user interface, based on their actions and surroundings.

The applications of this approach encompass scenarios where users interact with shared resources, such as printers, based on personalized profiles and preferences. The system demonstrates the capability to infer connections between users and resources, providing more intelligent and personalized interactions. User evaluations highlight the effectiveness of the adaptive features, although there is room for improvement in the interface design. This research offers a significant contribution by creating a more personalized and context-aware augmented reality experience that dynamically adjusts to user needs and the surrounding environment.

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2.4.4 Adaptive Multimodal Interaction in Mobile Augmented Reality Framework

The conceptual framework for Adaptive Multimodal Interfaces in Mobile Augmented Reality is a framework that provides a guideline to apply adaptive multimodal interaction in mobile AR (Abidin et al., 2017). The framework has three main components: input modalities, multimodal adaptation module, and AR module; based on components of previous models related to adaptive interfaces, multimodal interfaces and augmented reality. Users can interact with the AR system using various input methods, such as gestures, speech, and touch, allowing them to engage naturally with augmented content.

In addition to user inputs, the system adjusts based on environmental changes like light levels or noise. If the surrounding area is noisy, the system may prioritize visual interactions over voice commands, or it could automatically adjust screen brightness in dimly lit settings. This ensures the AR system remains responsive to the user's environment, providing a smoother interaction experience.

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Device-specific information, such as battery life or screen orientation, is also considered. If the device's battery is running low, the system can switch to power-saving modes, and the display adjusts automatically when the phone is rotated. These adjustments ensure the AR system remains functional and efficient, no matter the condition of the device.

The framework integrates input from various sensors, such as accelerometers and cameras, and processes them to determine the best way to respond. After processing, the system adapts the AR display by adjusting interaction modes or modifying the content presented to the user. Finally, the AR controller and view manager handle how

augmented content, like points of interest, is shown in real-time, ensuring the system continually adapts to the user's location and actions. Overall, this framework helps create adaptive AR systems that adjust automatically to user inputs and environmental conditions, making them easier to use and more efficient.

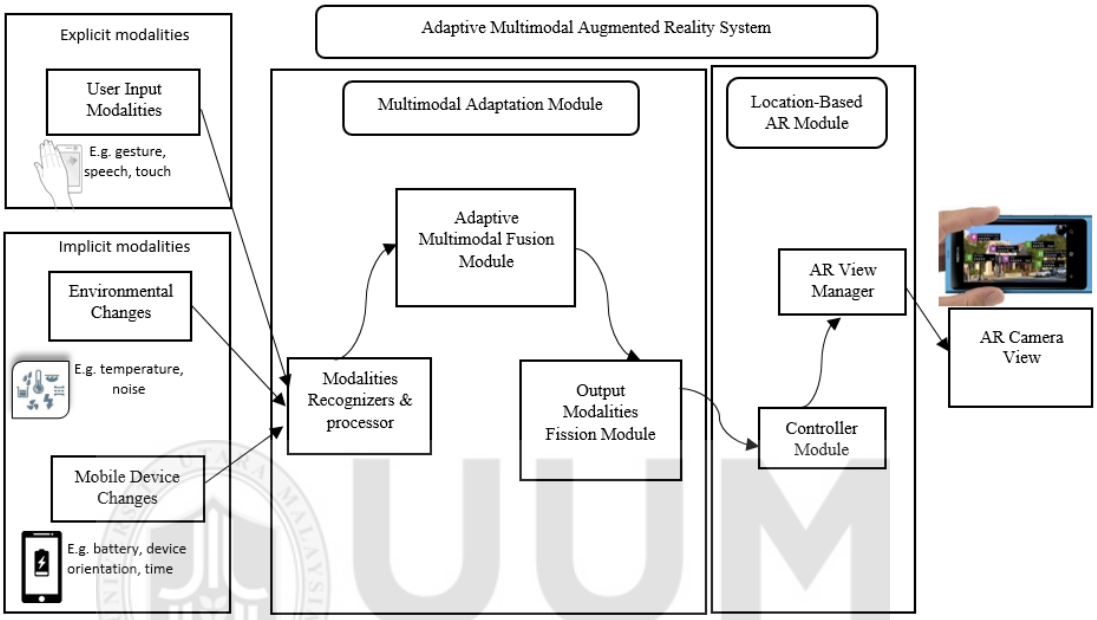


Figure 2.4. Conceptual framework for Adaptive Multimodal Interfaces in Mobile Augmented Reality

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2.4.5 Finding of AAR Components

Through an analysis of previous models, several recurring patterns and similarities were observed, highlighting key elements that consistently contribute to the effectiveness of adaptive Augmented Reality. Models such as ARtSENSE (Damala et al., 2012), the Context-awareness Adaptive AR Model (i-ARA) (Hervás et al., 2013) and Adaptive Augmented Reality (A^2R) (Tenemaza et al., 2015), share a common focus on enhancing user experiences through adaptivity and context-awareness. For example, ARtSENSE dynamically adjusts content based on real-time user engagement by integrating sensory inputs, such as visual and acoustic cues, tailoring the interaction

to individual preferences. Similarly, the A^2R model emphasizes the interaction between user data, contextual factors, and system responses to provide a seamless and personalized experience. Building on these concepts, the i-ARA framework employs context-awareness to adjust AR content dynamically, ensuring that it remains relevant to the user's environment and behavior.

Across these models, three consistent themes emerge. First, the interaction environment is a critical factor, with elements such as physical surroundings, sensory inputs, and contextual conditions shaping how users engage with AR systems. Second, user personalization plays a central role, where systems adapt to individual needs by leveraging user profiles, real-time behaviors, and environmental factors. Third, the integration of devices, technologies, and services is essential for supporting adaptivity, as demonstrated by frameworks like the Adaptive Multimodal Interaction model (Abidin et al., 2017), which uses diverse input methods and device sensor functions to enhance system capabilities.

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As depicted in Table 2.1, elements such as user profiles, media, interaction, environment data, and device components were identified as fundamental across these four frameworks. User profiles collect details like age, gender, height, and physiological conditions to tailor the experience, while the environment data uses sensor information (e.g., camera, GPS, compass) to adjust content dynamically. Media content (including multimedia elements such as images, videos, and 3D objects) is adapted based on both user preferences and environmental context. Interaction styles vary with device capabilities, supporting gestures, speech, touch, or visual inputs. Environmental adaptation further modifies visual, auditory, and interactive elements

Table 2.1 Components comparative analysis.

CORE COMPONENTS / MODEL	Environment (EV) medium, media, interaction, context (storytelling)	User Personalization (UP) biodata e.g., age, gender, height, etc.	Other Components (OC) service, network, devices
A2R Museum Augmentation Model Damala and Stojanovic (2012)	i) Digital multimedia contents ii) Gaze and gesture-based interaction	i) Bio sensing ii) Visual sensing iii) Audio sensing	Devices Sensors: i) Sensors from AR see-through glasses, Headset and microphone
Adaptive Multimodal Interaction in Mobile Augmented Reality Framework Abidin et al. (2017)	i) User input: gesture, speech, touch	i) Adaptation module	Devices Sensors: i) Environment changes e.g: Temperature, noise, GPS ii) Mobile device changes e.g: battery, orientation, time
Adaptive Augmented Reality Model Tenemaza, et al. (2015)	i) Interaction model ii) Environment model iii) Content model	i) User model: user profile, motion, objective task, knowledge / interest	Devices Sensors: i) Context model contain the information provided by device sensors. (GPS, the encompass, the image recognizer, the touch screen, etc.)
Context-awareness Adaptive AR Model Hervás et al. (2013)	i) Augmented object, multimedia	i) User ontology: user profile	i) Devices Sensors: compass, accelerometer

in response to real-world surroundings. The comparison concludes that adaptivity in AAR models depends on a user-centric and environment-aware approach, facilitated

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by device sensors and multimedia content, to deliver a responsive and personalized user experience.

The analysis of the adaptive augmented reality (AAR) models provided these groups of components: environment (EV), user personalization (UP), and other components (OC), like devices and network services.

Each model utilizes the Environment (EV) component to deliver context-aware interactions. For instance, the A2R Museum Augmentation Model focuses on media and storytelling contexts, integrating digital multimedia through gaze and gesture-based interactions. In contrast, the Adaptive Multimodal Interaction in Mobile Augmented Reality Framework includes environmental changes like temperature, noise, and GPS as part of its adaptivity strategy. This use of environmental data ensures that the user experience is dynamic and relevant to the surroundings.

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On the other hand, all models emphasize personalization by incorporating user biodata (such as age, gender, and height) into the interaction model, hence contributing to the user personalization (UP) component. The A^2R Model, for instance, uses a detailed user model that includes user motion, tasks, and interests to create tailored experiences. This attention to user-specific data enables the models to customize content in meaningful ways, enhancing engagement and user satisfaction.

The device sensors and network services play a critical role in enabling adaptivity, which is named as other components (OC). The A^2R Museum model leverages sensors from AR glasses, headsets, and microphones to capture visual and audio data, while the Adaptive Multimodal Interaction Framework accounts for mobile device

conditions, such as battery life and device orientation. This reliance on device-specific sensors is crucial for adapting content delivery to various interaction forms like touch, voice, and gesture.

These shared elements were synthesized into three essential components: Environment Components (EV), User Personalization Components (UP), and Other Components (OC) that providing a foundation for defining and implementing AAR systems. These are the definitions of the three components. Firstly, EV refers to the elements that shape the entire interaction environment, which include the communication medium, the media involved, and the contextual layer that holds user information such as profiles, locations, and conditions to support adaptive responses. Secondly, UP focuses on user specific information that allows the system to personalise the experience, drawing on profiles, locations, and real-time states so the interaction can adapt to individual needs and preferences. Lastly, OC represents the set of devices, technologies, and services that enable these interactions, ensuring smooth operation and strengthening the system's overall adaptability.

Together, these components form a cohesive framework for understanding and advancing AAR systems, emphasizing their adaptability to diverse environments, user needs, and technological capabilities. This structured approach ensures that AAR systems are capable of delivering personalized and contextually relevant experiences to the users in various application domains, especially in cultural heritage.

2.5 Design Framework for Smart Glass AR Experiences in Heritage Sites.

Dima (2022) proposes a prototype design framework for smart glass AR experiences, with an emphasis on the goal of creating meaningful and educational immersive heritage experiences through affective storytelling. The framework consists of three design pillars: Interpretation, Affective Storytelling, and Technology Considerations, which are considered during the design phase.

The Interpretation pillar focuses on the academic and curatorial aspects, including curatorial guidance, learning objectives, and the design of narratives, chronology, and archival material selection, ensuring historical accuracy and educational value. The Affective Storytelling pillar is vital for creating an emotional connection with the history, facilitating embodied meaning-making, as evidenced by participants describing sites as "alive" after the AR experience. Lastly, Technology Considerations addresses the practicalities of AR implementation, considering device capabilities, how technology enhances narrative through navigation and choreography, and the importance of usability and ergonomics for a seamless user experience.

The framework emphasizes that for heritage sites, which are intrinsically sensory environments, AR smart glasses offer a superior, hands-free, and more immersive alternative to cumbersome mobile devices, thereby facilitating an embodied and enactive experience that promotes situated learning. Furthermore, Dima (2022) argues that affective and emotional engagement, fueled by non-didactic narrative, is crucial as it has been empirically linked to increased motivation, attention, and long-term knowledge retention among visitors.

Table 2.2 Design framework for AR smart glass experiences

Design Pillar	Design elements
Interpretation (I)	a. Learning objectives b. Time navigation c. Archival material
Affective Storytelling (AS)	a. Historical Empathy b. Narration c. Visitor's role d. Viewer on and offboarding e. Agency f. Embodied cognition
Technology Considerations (TC)	a. Navigation mechanism b. Choreography (sequences, pace, movement in space) c. Sensorial input (gestures, gaze, eye tracking, directional sound)

(Source from: Dima (2022))

The evaluation of the case study "Sutton House Stories" confirmed that the use of AR with a strong narrative component allowed participants to feel a deeper, more emotional connection to the house's history, often describing the experience as the house came to life. Overall, the framework provides a valuable and necessary starting point for designers and researchers, successfully shifting the conversation from technological capability to affective and embodied learning outcomes in the heritage sector.

2.6 Cultural Heritage Augmented and Tangible Storytelling (CHATS)

Trichopoulos et al. (2021) present the Cultural Heritage Augmented and Tangible Storytelling (CHATS) platform, a system designed to enhance the visitor experience at cultural heritage sites using personalized digital narratives under a tangible interface. The primary objective was to develop a system that integrates state-of-the-art visualization techniques like Augmented Reality (AR) and Smart Glasses with context-aware and personalization methods. This approach aims to tailor cultural information

based on the user's profiles and interests, making the experience more engaging. The work is conceptually grounded in Digital Storytelling, which integrates images, music, narrative, and voice to give dimension to characters and experiences. It also uses the idea of a Tangible Narrative, a form of interactive digital storytelling that uses physical objects to augment the visitor's experience and impart meaning. Context-awareness addresses the requirement of tailoring the experience by collecting user data and environmental parameters, which in the cultural space domain includes location, profiles, user movement, and behavior.

The CHATS system employs a hybrid architecture combining contemporary technology with tangible artifacts. At its core is a sensory network, operating under the Internet of Things (IoT) paradigm, using sensors to detect proximity and interactions (such as touching objects) and actuators to manifest the platform's reaction (like playing sounds). The architecture consists of four main modules: the Localization Module uses BLE (Bluetooth Low Energy) technology via a tag carried by each visitor to capture location and behavioral data. This information is used by the Digital Storytelling (DS) Module to trigger appropriate actions. The Personalization Module identifies the user's persona and profile, providing output to the DS Module to ensure a personalized experience. The central DS Module analyzes all incoming data and delivers the appropriate augmented content to the user.

To test the architecture, a case study was implemented using the painting "Children's concert" by George Jacovides. A diorama was constructed using 3D-printed characters and objects to create a tangible representation of the scene. Arduino Mega 2560 controllers were embedded within the models, utilizing sensors such as ultrasonic distance sensors, a capacitive touch sensor, and Bluetooth BLE beacons. The

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interaction is layered: the first level is involuntary, where the visitor's BLE tag automatically pairs, triggering a welcome audio message. The second level is active, where users entering the area or touching the models trigger short, sound-based narratives that are dynamically adapted based on the user's actions and the presence of multiple people. The augmented content is delivered immersively using AR smart glasses combined with binaural audio recordings.

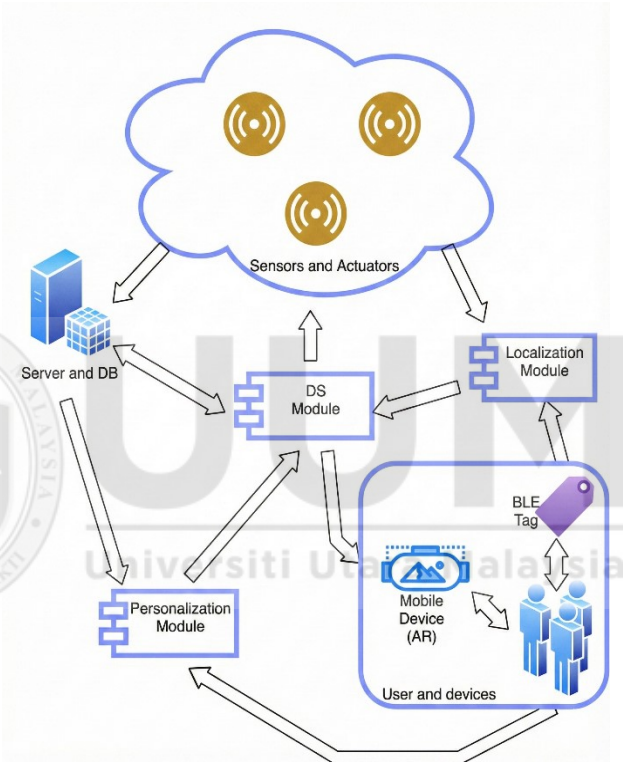


Figure 2.5. CHATS architecture

The platform successfully demonstrates a feasible, low-cost, and expandable framework for personalized digital storytelling using tangible objects. The system's ability to combine tangible interaction with context-aware data, AR visualization, and binaural audio creates a dynamic and immersive environment that augments the cultural user experience. The proposed architecture allows for new and stimulating implementations of digital storytelling associated with the scene. The conclusion is that CHATS offers a viable approach to personalized digital storytelling through

tangible interaction. The study did not include extensive user field testing or direct input from cultural heritage professionals, which limits the depth of validation needed to be addressed in future work to strengthen the model.

2.7 Reference Architecture for Gamified Cultural Heritage Applications

Martusciello et al. (2025) propose a conceptual reference architecture aimed at enhancing Cultural Heritage (CH) applications through the systematic integration of Gamification (GAM), Generative Artificial Intelligence (GAI), and Augmented Reality (AR). This framework seeks to address the fragmentation prevalent in current digital heritage applications, which often suffer from limited interactivity, personalization, and adaptability, thereby reducing user engagement. By combining these three technologies into a scalable and adaptive framework provide an intelligent, responsive application experiences that promote deeper user appreciation and broaden accessibility.

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The proposed model is a Conceptual Reference Architecture comprising four key subsystems: the Mobile App (a), the Gamification Engine (b), the Generative AI Module (c), and the Augmented Reality System (d). The Mobile App functions as the user interface, employing a Path Execution Engine to guide visitors through dynamic, graph-based journeys. The Gamification Engine oversees game mechanics, monitors progress via points and leaderboards, and transmits engagement data to the AI module. Central to personalization, the Generative AI Module utilizes Machine Learning (ML) and Large Language Models (LLMs) within an AI Recommender System and Journey Path Creator to dynamically generate and optimize exploration paths based on user behavior. The Augmented Reality System merges virtual and real-world elements

through a Tracking System and virtual-real mixer, providing immersive, context-aware digital overlays. Integration across these components is supported by a hybrid microservices and event-driven architecture, ensuring real-time performance and seamless synchronization.

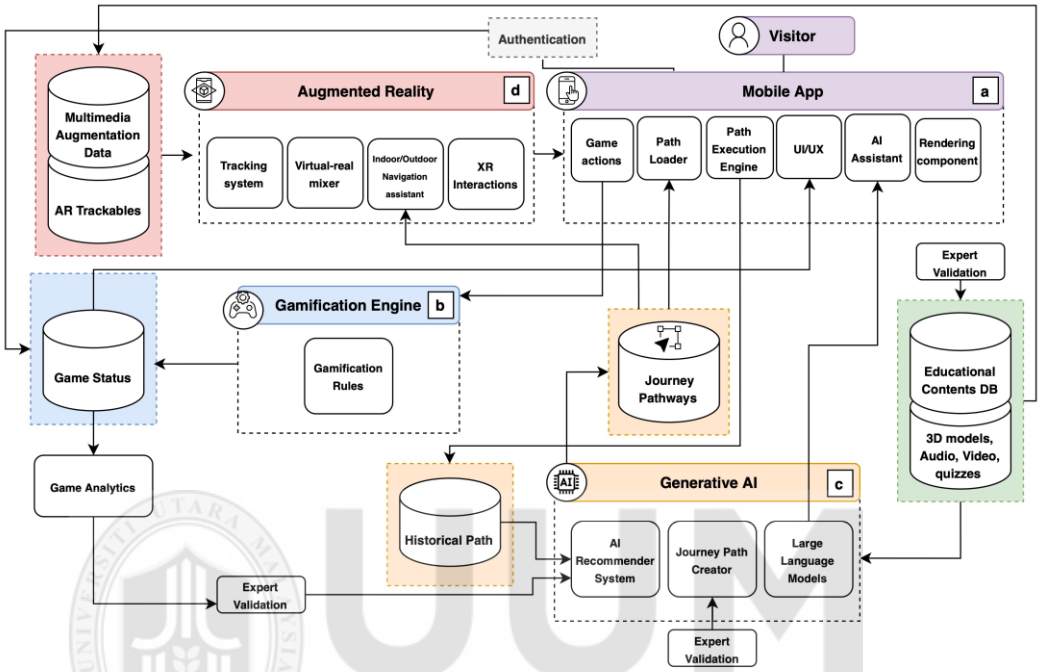


Figure 2.6. Reference Architecture for Gamified Cultural Heritage Applications (Source: Martusciello et al. (2025))

This study proposes a structured blueprint that integrates three advanced technologies, aiming to fill a gap in existing unified frameworks. However, the framework is currently presented only at the conceptual and component level, which requires validation and user testing in future research.

2.8 Conceptual model of mobile augmented reality for cultural heritage

Pendit and Zaibon (2014) provide a model as a guideline to develop a mobile AR application for experiencing non-formal, enjoyable learning while visiting a cultural heritage site. The model had been proposed after reviewing the existing model and realizing that the previous model did not include the element of enjoyable informal

learning. This model had incorporated learning theories toward AR application components (such as media elements, activity, navigation, social interaction, games and presentation style) and mobile technology component to holistically visualize the concept of enjoyable informal learning in mobile augmented reality model (refer to Figure 2.7).

The conceptual model for mobile Augmented Reality (AR) in the context of cultural heritage, with a focus on facilitating enjoyable informal learning, encompasses three crucial dimensions. First and foremost are the foundational theories that underpin the pedagogical approach. Drawing from the rich landscape of educational theories such as Multimedia Learning theory, mindfulness theory, constructive theory, situated learning theory, experiential learning theory, and collaborative learning theory, the aim is to create a dynamic learning environment that engages users cognitively, emotionally, and socially. These theories inform the design and implementation of the AR experiences, aligning them with established principles of effective learning.

The second dimension involves the careful structuring of content to optimize the learning experience. This encompasses various elements such as the opening sequence to grab the user's attention, the incorporation of diverse media elements, interactive activities, intuitive navigation mechanisms, opportunities for social interaction, gamification elements, and a compelling presentation style. The seamless integration of these components aims to enhance user engagement and ensure that the learning process is both enjoyable and effective.

The third dimension centered around leveraging mobile technology to augment the learning experience. This includes harnessing the capabilities of mobile devices, such

as the compass, camera, sensors, GPS, database integration, tracking functionalities, rendering capabilities, wireless networking, and registration systems. These technological components collectively contribute to creating an immersive and context-aware AR experience, allowing users to explore cultural heritage in a manner that goes beyond traditional educational approaches.

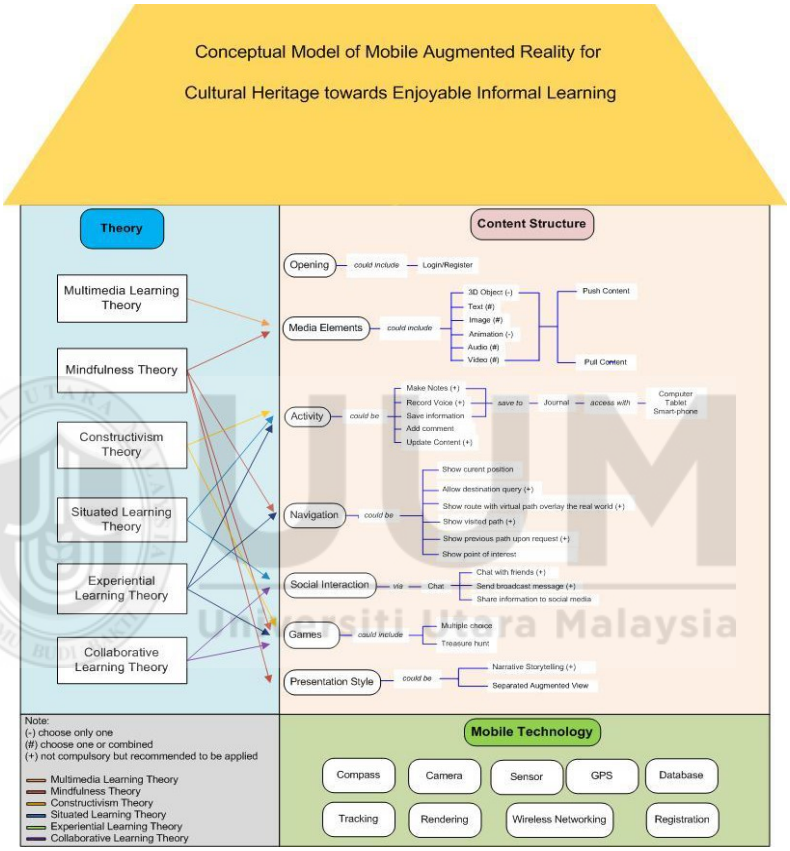


Figure 2.7. Conceptual model of mobile augmented reality for cultural heritage towards Enjoyable Informal Learning (Source: Pendit and Zaibon (2014))

Media elements in this model mention that the media used in producing a mobile AR could include multimedia elements such as image, text, audio, video, animation, and 3D objects. These media can be used to enhance the content's explanation, and it could be push content or pull content. Push content is useful for delivering timely information and notifications to users, keeping them updated without their active

involvement. Pull content, on the other hand, gives users control over what information they want to access, allowing them to retrieve specific content when needed. The choice between push and pull depends on the nature of the application, the type of content being delivered, and the user's preferences. In presentation style, the content could be narrative storytelling or an augmented view of the stories. User could also provide input in the AR application through activities such as making notes, adding descriptions, comments and updating them. This is also a collaboration element whereby the user is able to interact and share information with other users through social media. Talking about interaction, AR can also be in the form of games like multiple choice trivia or treasure hunt games. One of the important parts of this AR model is the navigation elements. These could show the position of the user and guide the user to the potentially interesting point to visit. Furthermore, the route is overlaid on the real world to lead the path toward the destination.

In conclusion, this model shows potential for developing mobile AR applications for informal learning at cultural heritage sites. It offers a forward-thinking framework that considers the changing educational technology landscape and modern learners' preferences, contributing to immersive learning experiences through mobile AR technology. This research on utilizing mobile augmented reality for informal learning at cultural heritage sites may have a gap in personalizing the AR experience for diverse visitors. The model could benefit from placing greater emphasis on adaptive learning, tailoring the experience according to individual learning styles, prior knowledge, and cultural background (Bitonto et al., 2010). Additionally, while the model covers various aspects of learning and engagement, it might not fully delve into storytelling. Storytelling is essential in cultural heritage education to bring history and culture to

life interactively. Integrating narrative techniques into the AR experience can enhance its effectiveness by ensuring that stories are engaging and educational. Incorporating adaptation mechanisms and narrative strategies into the AR experiences could greatly improve personalized learning outcomes as well as visitor satisfaction. This improvement is crucial for the long-term success of AR applications in cultural heritage settings.

2.9 SituAR Model

SituAR is a model that provides components for producing AR content using storytelling and gamification elements (Vera & Sánchez, 2016). SituAR model consists of five main components, which are: social media, storytelling, gamification, augmented reality and multimedia (as depicted in Figure 2.8).

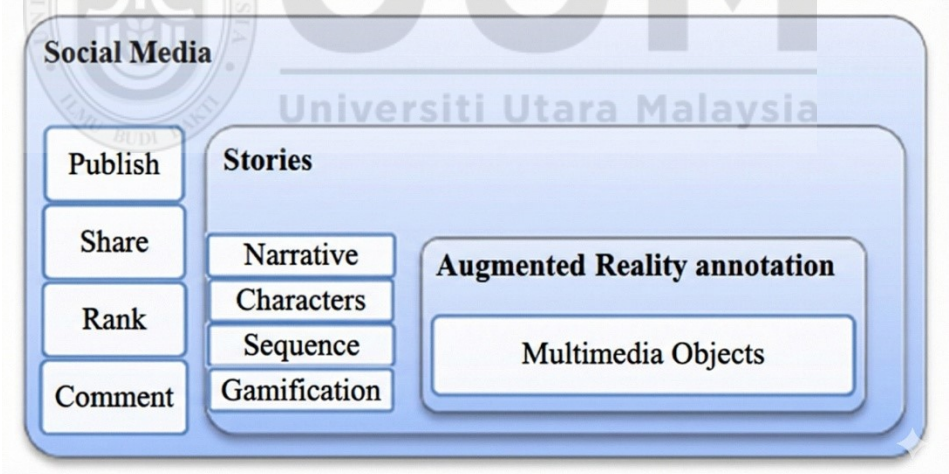


Figure 2.8. SituAR Model

The model tries to increase the user experience of using AR in promoting cultural heritage by allowing the user to compose the story. Stories can be composed using multimedia and 3D models. Narrative, characters, and Sequence were highlighted as significant elements to create the story, while gaming elements were added to enhance

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the storytelling. These features allow the user to produce their own story of a particular point of interest and gain points when creating stories and interacting with other users' stories. Furthermore, the interactions are also supported by social media, as the user was able to publish, share, rank and comment on social media platforms. A high-end prototype had been produced based on the proposed component to evaluate the model. The prototype allows users to produce stories and AR content instead of just viewing them, yet it still lacks empirical evidence.

2.10 Four-Stage Conceptual Model of Virtual Heritage Preservation.

Bec et al. (2019) proposed a model to guide usage and manage mixed reality in heritage. The conceptual model of virtual heritage preservation for tourism experience suggests that heritage content can be presented as "Historical Facts, Contested Heritage, Integrated Historical Facts and Contested Heritage, and Alternate Scenario."

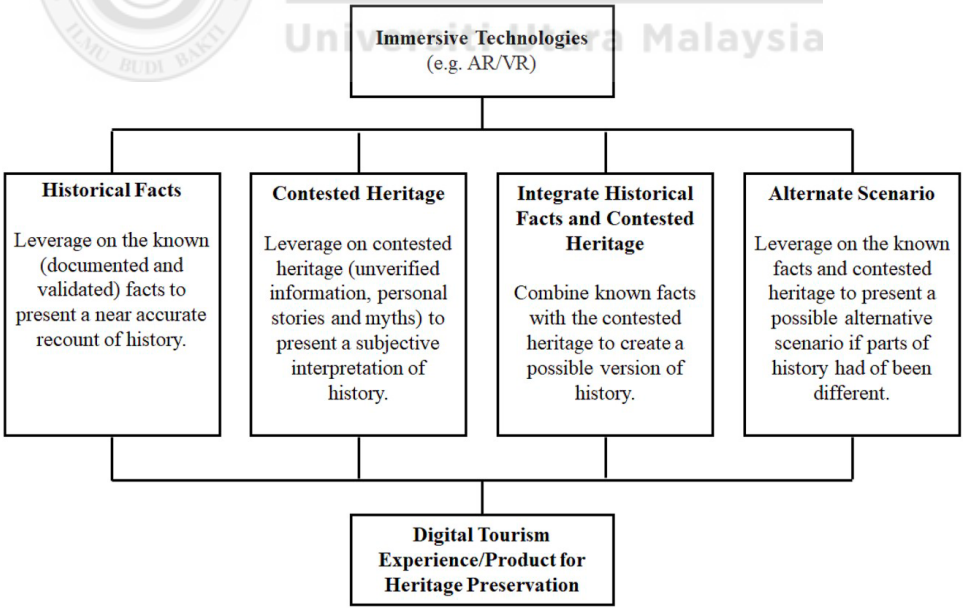


Figure 2.9. Four-stage conceptual model of virtual heritage preservation for tourism

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This model AR and validated information from a reliable source. 2) Based on non-scientific validation information (such as cultural stories, myths or legends). 3) mixture of fact and fictional information, and 4) presentation of alternate realities that could happen based on factual data. The model has provided four possible types of story content to be incorporated in AR/VR development for heritage. However, the model has not been evaluated empirically.

2.11 User Experience Model of Markerless Augmented Reality Applications

Hammady, Ma and Powell (2018) proposed a User Experience (UX) model of a marker-less augmented reality application for the museum in England and Egypt. The proposed model is a guideline to develop an AR application for a museum that focuses on optimized user experience while visiting the museum. There are three main phases in this model, which are requirements, design and evaluation (Figure 2.10).

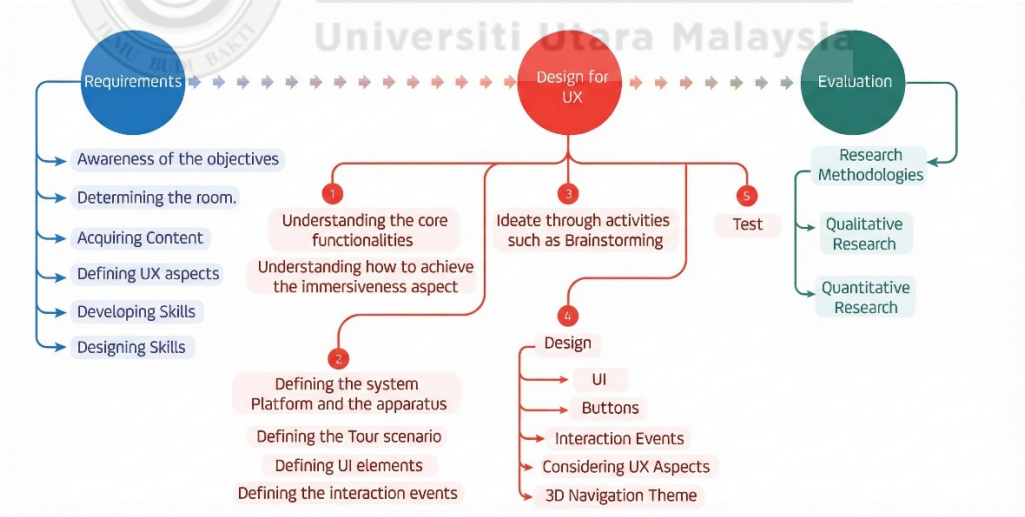


Figure 2.10. UX Design Process Model

The first stage in this model is the requirements phase. This phase is essential for gathering fundamental information, including the objective of the application,

determining the room size, acquiring relevant and suitable content, developing and designing necessary skills, and finally defining UX aspects. The next stage is the design phase. This phase focuses on achieving the intended user experience based on the requirements defined in the first stage. The first step in this stage is to understand the main function and the methods to accomplish it. Then, the platform, UI elements, scenarios, and events to be included in the application are identified. The third step is to plan (brainstorm) the elements identified in the previous step. Ideation is carried out in step four, which involves designing. This includes creating the user interface (UI), buttons, interaction events, and thematic elements while considering UX aspects (explained further in the next paragraph). This stage concludes with testing the prototype for bugs and errors. The final stage in this model is the evaluation phase, which involves experts reviewing and commenting on the prototype using both qualitative and quantitative methods. The next paragraph discusses the UX aspects of the model.

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2.11.1 UX aspects for mobile augmented reality application

Hammady, Ma and Powell (2018) had further discussed two main aspects of user experiences in mobile augmented reality, which are Utilitarian and Visual (Figure 2.11). Utilitarian covers the context of the functionality of AR and mobile phones, and interactability. The visual aspect discusses the aesthetic level of the application. These two aspects would influence users' enjoyment, motivation, satisfaction and productivity (Hammady et al., 2018).

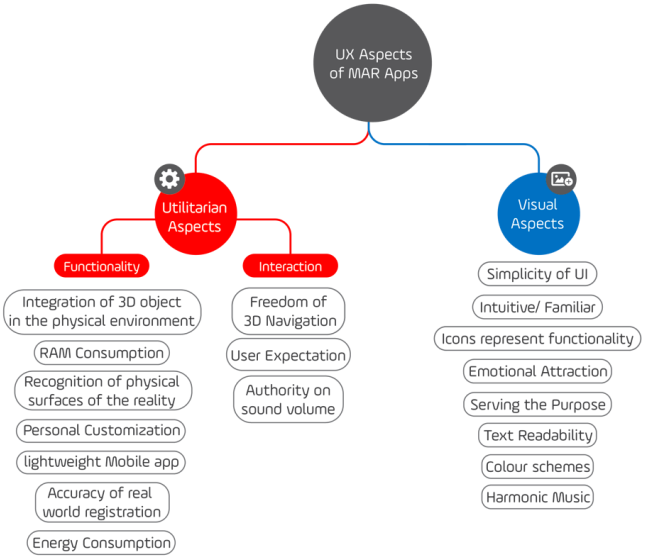


Figure 2.11. UX Aspects of the mobile augmented reality model

In conclusion, the UX design process model was adapted as the methodology for developing the prototype in this study, and UX aspects were key components in encouraging users to engage with the AR application at the heritage site. Furthermore, the next section presents the method used to evaluate user acceptance of AR.

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2.12 Conceptual Model of Digital Storytelling

The conceptual model of digital storytelling provides core elements as a guideline to produce digital storytelling (DST), which could be in the form of interactive or non-interactive (Tenh, 2013). The core elements can be categorized into four different clusters (construction, appeal, origin and interaction), and each element has its roles in both forms of storytelling.

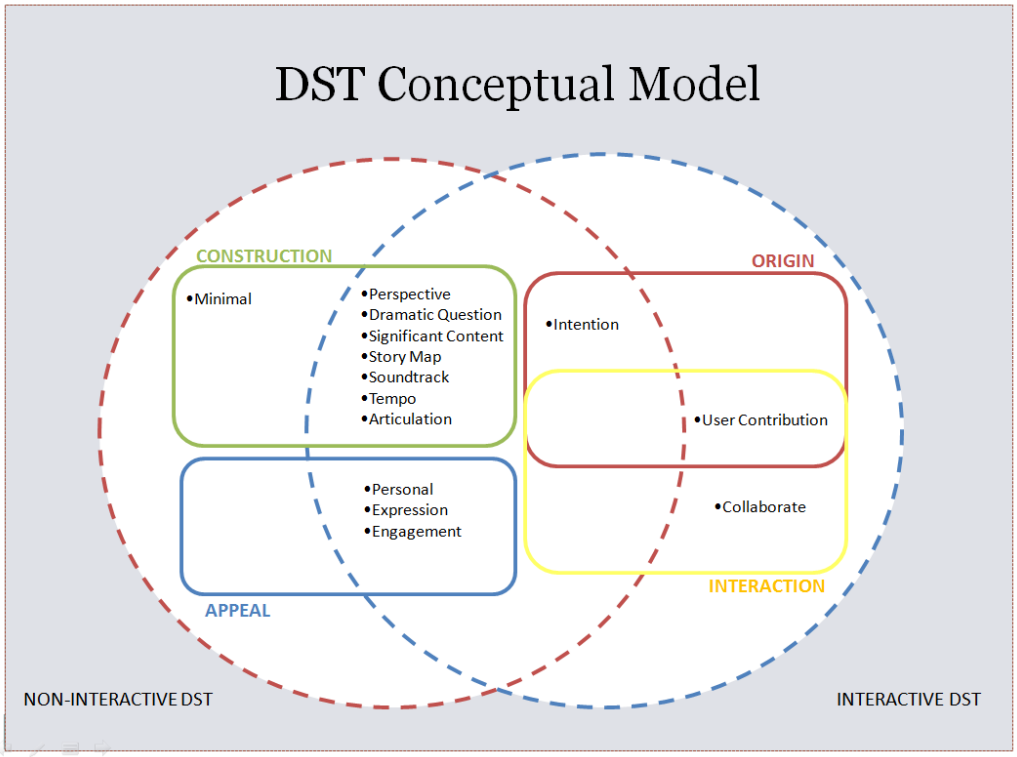


Figure 2.12. Conceptual Model of DST (Tenh, 2013)

The Construction cluster in digital storytelling (DST) comprises eight key elements: minimal (keeping stories concise by focusing on essential content), perspective (conveying messages through specific viewpoints), dramatic question (creating suspense to maintain audience interest), significant content (prioritizing the story over multimedia), story map (following a classic storytelling arc), soundtrack (using music to evoke emotions), tempo (maintaining rhythm to retain interest), and articulation (leveraging the storyteller's voice for impact). The appeal cluster emphasizes personal connection, expression through symbolic or non-verbal communication, and audience engagement to make stories relatable and captivating. The Origin cluster includes intention (starting with a purpose revealed at the end) and user contribution, which, along with collaboration in the Interaction cluster, enables audiences to shape and co-create digital storytelling experiences. These elements collectively enhance the

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creation, impact, and interactivity of digital storytelling. Since storytelling in AR can be interactive or non-interactive, the conceptual model was taken into consideration in this study.

2.13 Storytelling in Cultural Heritage

The implementation of multimedia presentations, augmented reality (AR) and virtual reality (VR) has been applied in the cultural heritage field, as can be observed in the display of artifacts in museums, art galleries, and even maritime archaeological artifacts. In the museum, exhibit items are curated to form the storyline according to the context of each exhibition to deliver the message to the visitors (Damala et al., 2013; Vassilakis et al., 2018). Storytelling has also been adapted within the technologies to motivate participation and enhance the experience of the user visiting the museum or heritage site. For example, the public user has access to historical artifacts through the "ESRI ArcGIS platform", and the system is able to re-tell the story behind the artifacts (Alemy et al., 2017).

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Storytelling is a timeless art form that has been employed for centuries to transmit knowledge, wisdom, and cultural values across generations. It serves as a compelling communication tool capable of entertaining, educating, and inspiring audiences. Storytelling manifests in various forms, including oral, written, and visual mediums, and can be delivered through spoken word, literature, theatrical performances, films, and other creative expressions. However, for the purpose of this study, the focus is on digital storytelling, which refers to the use of digital media like photos, audio, videos, and 3D objects to convey a story in a digital format (Lambert, 2006; Ohler, 2008; Tenh, 2013). AR technology has allowed for the creation of more immersive and interactive

storytelling experiences by superimposing digital content onto the physical world. The use of storytelling in AR technology can make heritage site visits more captivating and informative, enabling visitors to experience the exhibits in a whole new way.

AR technology, with the inclusion of digital storytelling elements is the right combination for cultural heritage information presentations (Fenu & Pittarello, 2018). The historical material and documents are important to historians or researchers. However, integrating these materials (such as documents, photos, videos) through technologies allows the public to access and enjoy the story from history (Goy et al., 2015). Additionally, personalization and emotional engagement are fundamental elements in the art of storytelling, particularly within digital narratives. Emotion serves as a crucial mechanism for capturing audience attention and fostering a deeper connection with the story, thereby enhancing the overall impact and effectiveness of digital storytelling (Lambert, 2006; Ohler, 2008).

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Various storytelling methods have been applied in the cultural heritage and museum exhibitions. For example, in the *exhiSTORY*, stories of the exhibition are tailored according to the visitor's identity, preferences, interests, and style (Vassilakis et al., 2018). Labels or panels are usually used in the museum to display all exhibition information, and they might be limited and not relevant to some visitors. The story is present through a personal device incorporated with the technologies of the Internet of Things (IoT) and semantics. The semantics linking items in the exhibition help form the story, while each story form could be different depending on the visitor. The need for personalization and storytelling in cultural heritage has been highlighted and has been applied in this study.

Similarly, in “Gossip at palace” a geo-based museum exploration and history learning mobile game used virtual avatar in storytelling progression and exposed the user to relevant information (Rubino et al., 2015). The identity of the avatar depends on gender, social status, and personal inclinations. Furthermore, scores and rewards are given based on the exploration of the museum and interaction with the avatar as an encouragement to the user. The result of this study shows that storytelling and the gamification method have good potential for learning purposes. Gamification manages to give youngsters enjoyment and encourages them to explore the museum, while storytelling delivers information about the content effectively to the adult.

While Dusi, Ferretti and Furini (2017) proposed a “transmedia storytelling system” to preserve and tell the historical stories of a town in Italy, Reggio Emilia, through the collection of amateur videos. More than 500 hours of videos from an archive in Reggio Emilia were selected and edited into 120 clips of between 30 and 60 seconds in the mobile app version and web-based version. The collections of videos are categorized by theme and route, then tagged to their location. This mobile-based video database has a collection of private videos between the years 1940 and 1989. The system allows the user to see the story, ways of life and architectures of the location on the previous day. Evaluation of the system has been done with a group of 116 volunteer participants. The result shows that the system had increased youngsters’ interest in history, especially in those who have no interest in history. This again is evidence that storytelling plays a vital role in evoking interest in history.

On the other hand, Rizvic (2015) applied digital storytelling in an interactive virtual presentation for the Museum of Sarajevo. The presentation was made in three forms:

Documentary story, interactive story, and a serious game based on the previous survey. A presentation about *Talishan* that is made up of old photos, videos, graphic illustrations, and a 3D animated model. However, storytelling is the element needed to immerse the user in the moment of the past, even though a realistic, high-quality 3D visual is used (Rizvic, 2015). This is evidence that storytelling can immerse visitors in cultural heritage visiting, and some users choose interactive over linear storytelling. Interactive storytelling can be implemented in many forms, one of which is through a virtual museum.

Virtual museum has been introduced to overcome the limitations faced in the physical museum, such as insufficient space, not being able to display or limited access for fragile items, and not being interactive since the artifact cannot be touched (Wang, 2018). According to Wang (2018), virtual museum research has been done relating to digitizing exhibitions, re-modelling of ruins, and the enhancement of visitor experience. For this reason, he is investigating a virtual exhibition framework for a historical event where the Chinese army was crossing the border to assist Korean in a war against the United States of America. Two motivations that drive him to develop this project are: to convey maximum information about the event by presenting the exhibit using the photogrammetric method. Second, to cultivate youngsters' interest in history with virtual reality. Visual narrative was applied to guide and engage the user in the virtual exhibition in this study. The proposed framework involves visual elements (graphics, avatars, audio and video clips) in various formats to assist user navigation and, most importantly, a better understanding of the history. A simple survey on content understanding, engagement and technological usability was done with 26 undergraduates and 19 high school students. The survey has shown a positive

result, where the participants had a better experience using the virtual exhibition compared to a traditional museum or official website. The virtual narrative exhibition has achieved its purpose of cultivating the interest of youth in history by providing an exciting and engaging experience to the user.

On the one hand, the Alternative Reality narrative (AltR) is claimed as a new form of storytelling introduced for cultural heritage exhibition called "*New Pholiota"* (Hoang & Cox, 2018). Google Cardboard VR was used to allow the user to easily switch from a virtual and real environment, which "interweaves" a narrative that allows the user to link and compare an infamous historical architecture named *Pholiota* to the virtual image of it applied in modern design. Despite the high positive feedback from the exploratory study conducted through observation, selected participants underwent a survey and a semi-structured interview. The narrative in this research focuses on the experiences of comparing and connecting the physical and virtual content through alternating between different realities (Hoang & Cox, 2018).

For maritime archaeology, storytelling has been used in Virtual Reality (VR) to reveal the ruins under the sea. Reunanen, Díaz, and Horttana (2015) developed an immersive VR to preserve the wreck of Vrouw Maria, a Dutch merchant ship, in a maritime museum. The user was able to explore and interact around the wreckage using their body movement. The storytelling of the VR System is produced based on the information gathered by the archaeologist, such as the environment under the sea and the significant milestones of the wreckage. There is another VR storytelling project to exploit underwater cultural heritage called Virtual and Augmented Exploitation of Submerged Archaeological Sites (VISAS). VISAS is an edutainment based virtual

reality system that brings the user to the underwater archaeological site of south Italy through the narrative of virtual guide (Bruno et al., 2018). Bruno et al.(2018) also suggested that as a part of a serious game, the system contains three main elements: exploration, interaction and storytelling. Storytelling was applied in the system to guide the user to progress and interact with the Point of Interest (POI) in the scene.

In addition, Svevo Tour is applying storytelling in AR to explore the implications of storytelling in AR. In the initial evaluation, first-person storytelling has been the cause of the user's emotional engagement while using the application (Fenu & Pittarello, 2018). Svevo Tour is a project that applies storytelling in AR for the literary museum to promote famous Italian novelist, Italo Svevo. This project was initiated by the museum management so that the visitors can have a full experience of their collection inside and outside of the museum, including iconic landscapes related to the novelist. Surprisingly, the elderly visitors are accepting AR, as the audio-visual content emotionally engaged them more compared to textual content (Fenu & Pittarello, 2018). It is safe to say that first-person audio and visual storytelling able to emotionally connect the visitor toward the exhibition compared to text. A questionnaire was used in a comparative user study to evaluate user satisfaction with usability and enjoyment between semi-immersive and immersive environments. The participants are among groups of pre-teens, teens, and adult users. The result shows a high satisfaction level for both environments from all groups of participants, even among kids and inexperienced users. As a conclusion, these studies are showing a good indicator that personalization of storytelling according to the visitor's preferences, interests, and style could enhance their experience.

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Storytelling has been applied in various media for heritage sites on land and at sea. Some are using audio-video presentation, AR and VR, while others embed gamification to attract the visitors. Whether photos, videos, graphic illustrations, or even 3D models are used to show the information about the history or artifacts, storytelling is the element that heightens the interest of the user. Studies show that storytelling enhances user engagement and motivation, inspiring a deeper interest in learning about cultural heritage (Dusi et al., 2017; Fenu & Pittarello, 2018; Rizvic, 2015; Rubino et al., 2015; Wang, 2018).

These studies discussed above have been applying storytelling in a heritage context, mostly focusing on investigating the implications and user experience, but not providing these AR models with storytelling elements. Even though the storytelling context is not being discussed in detail, these studies demonstrate that storytelling is a vital element in engaging and inspiring users to explore and learn about cultural heritage sites.

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2.14 Comparison of Previous AR Models

Table 2.2 shows the comparison of previous AR models used for different contexts. ARtSENSE Adaptive Augmented Reality (A2R) Model by Damala and Stojanovic (2012) and the ontological context-awareness model by Hervás et al. (2013) emphasized adaptivity as the foundation of AR design. These frameworks prioritized the system's ability to respond to environmental and contextual information, thereby tailoring experiences to individual users. By integrating adaptive mechanisms, these models sought to create more dynamic, responsive, and meaningful interactions in AR environments. In parallel, Tenh (2013) introduced a conceptual model of digital

storytelling that, although not explicitly grounded in AR, underscored the role of narrative in enriching digital experiences. Together, these early contributions laid the groundwork for combining adaptive technology with storytelling practices.

AR research began to broaden its scope into the domains of cultural heritage and tourism. Pendit and Zaibon (2014) presented a conceptual model of mobile AR aimed at promoting enjoyable informal learning in cultural heritage contexts. This framework demonstrated how AR could serve as an engaging tool for cultural education, even though it lacked adaptive or storytelling components. Building on this, Tenemaza et al. (2015) revisited the A^2R model, reinforcing the importance of adaptive functionality to personalize user experiences. Vera and Sánchez (2016) introduced the SituAR Model, which directly combined AR with storytelling. Their approach highlighted how embedding narratives within AR could create more immersive and emotionally engaging experiences, particularly in tourism and heritage applications. This period marked a shift from purely technical adaptivity toward the integration of cultural and narrative dimensions.

Abidin et al. (2017) proposed an adaptive multimodal interaction framework for mobile AR, enabling users to engage with applications through diverse modes of input. This improved personalization by addressing different user needs and preferences in real time. Meanwhile, Hammady et al. (2018) introduced a user experience model specifically designed for markerless AR applications. Their framework emphasized seamless interaction, usability, and satisfaction, shifting attention explicitly toward UX. By removing the reliance on physical markers, this model streamlined AR

interactions, reflecting a growing recognition that technological sophistication must be matched with intuitive and accessible user experiences.

Table 2.3 Comparative Analysis of nine AAR and Frameworks

Year	***Authors***	***Model/Framework***	***Augmented Reality***	***Storytelling***	***Adaptive***
2012	Damala & Stojanovic	ARtSENSE Adaptive Augmented Reality (A^2R) Model	✓		✓
2013	Hervás et al.	Ontological Context-awareness for Adaptive AR Model	✓		✓
2013	Tenh	Conceptual Model of Digital Storytelling		✓	
2014	Pendit & Zaibon	Conceptual Model of Mobile AR for Cultural Heritage (Informal Learning)	✓		
2015	Tenemaza et al.	Adaptive Augmented Reality (A^2R) Model	✓		✓
2016	Vera & Sánchez	SituAR Model	✓	✓	
2017	Abidin et al.	Adaptive Multimodal Interaction in Mobile AR Framework	✓		✓
2019	Bec et al.	Four-stage Conceptual Model of Virtual Heritage Preservation for Tourism	✓	✓	
2021	Trichopoulos et al.	Cultural Heritage Augmented and Tangible Storytelling (CHATS)	✓	✓	✓
2022	Dima	Design Framework for Smart Glass AR Experiences in Heritage Sites.	✓	✓	✓
2025	Martusciello et al.	Reference Architecture for Gamified Cultural Heritage Applications	✓	✓	✓

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Bec et al. (2019), proposed a four-stage conceptual model for virtual heritage preservation in tourism. This model integrated AR with storytelling to preserve cultural heritage while engaging tourists through immersive narratives. By combining narrative elements with AR environments, it strengthened emotional resonance and supported the transmission of cultural values.

Trichopoulos et al. (2021) developed the Cultural Heritage Augmented and Tangible Storytelling (CHATS) platform to enhance visitor experiences at cultural heritage sites using personalized digital narratives delivered via a tangible interface. This system integrates contemporary visualization techniques, such as Augmented Reality (AR) and smart glasses, with context-aware personalization to tailor information based on user profiles, interests, location, and behavior. Conceptually, CHATS is grounded in Digital Storytelling and the use of Tangible Narrative, where physical objects augment the experience. The system employs a hybrid architecture, rooted in the Internet of Things (IoT) paradigm, using a sensory network (BLE tags, sensors, and actuators) to detect user proximity and physical interaction with tangible artifacts. The four core modules—Localization, Personalization, Digital Storytelling (DS), and a physical tangible interface—work together: the Localization Module gathers visitor data (via a BLE tag), the Personalization Module profiles the user, and the central DS Module processes this information to trigger and deliver dynamically adapted augmented content (immersive AR visuals and binaural audio). Tested successfully using a 3D-printed diorama of the "Children's concert" painting, CHATS provides a feasible, low-cost framework for personalized, immersive, and interactive cultural experiences. However, the initial study's lack of extensive user field testing limits its full validation.

Dima (2022) proposes a three-pillar design framework for creating engaging, educational Smart Glass Augmented Reality (AR) experiences at heritage sites. The first pillar, Interpretation, ensures academic rigor by focusing on curatorial guidance, learning objectives, and selecting historically accurate archival material for the narrative. Second, Affective Storytelling aims to build an emotional connection with the site's history, facilitating embodied meaning-making, which is empirically linked to increased visitor motivation and long-term knowledge retention. Finally, Technology Considerations addresses implementation practicalities, including device capabilities, narrative enhancement through choreography and navigation, and the usability of the smart glasses. By offering a hands-free, immersive experience, this framework emphasizes how AR smart glasses enable embodied and enactive situated learning superior to mobile devices in the sensory environment of heritage sites.

Martusciello et al. (2025) propose a Conceptual Reference Architecture to overcome the fragmentation and limited user engagement typical of current digital heritage applications by systematically integrating Gamification (GAM), Generative Artificial Intelligence (GAI), and Augmented Reality (AR). This scalable framework aims to provide intelligent, responsive, and personalized application experiences. The architecture is composed of four interconnected subsystems: the Mobile App serves as the user interface, guiding visitors through dynamic journeys; the Gamification Engine manages game mechanics and tracks progress; the Generative AI Module uses Machine Learning (ML) and Large Language Models (LLMs) to dynamically generate and optimize personalized exploration paths; and the Augmented Reality System provides immersive, context-aware digital overlays. Integration is achieved through a hybrid microservices and event-driven architecture, ensuring real-time performance.

While the study offers a structured blueprint for unifying these advanced technologies, the framework is currently only conceptual and requires future validation and user testing.

A significant number of models emphasized adaptivity as the cornerstone of their design. Frameworks like the ARtSENSE Adaptive Augmented Reality (A2R) Model, the ontological context-awareness model, and the adaptive multimodal interaction framework all focused on personalizing AR experiences according to contextual and user-specific information. These approaches ensure AR applications can dynamically respond to changing environments, preferences, or interaction patterns, thereby increasing relevance and user engagement. Such responsiveness is particularly important in mobile and heritage applications, where users interact with diverse content in real-world contexts. Several frameworks placed storytelling at the heart of AR experiences. Models such as the SituAR Model, the four-stage conceptual model of virtual heritage preservation, and the conceptual model of digital storytelling demonstrated how narrative serves as a bridge between technology and culture. Through storytelling, AR transforms from a simple information delivery tool into a medium for cultural transmission, education, and tourism engagement. These narrative elements evoke emotional connection, enhance immersion, and create memorable experiences, particularly crucial in cultural heritage and tourism contexts. While all reviewed models highlight the importance of creating adaptive and story-driven AR experiences, and recent frameworks like CHATS (2021), Dima's Design Framework (2022), and Martusciello et al.'s Reference Architecture (2025) have achieved conceptual integration of AR, storytelling, and adaptivity, a critical gap remains in their empirical validation and scalability. The descriptions show that these

comprehensive models either lack extensive user field testing or are currently only conceptual blueprints.

Therefore, the synthesis underscores that future AR frameworks must move beyond conceptual novelty by achieving widespread practical implementation and rigorous validation of a truly integrated and user-centered model. Addressing this gap is necessary for AR to become a transformative tool that successfully aligns adaptive personalization with narrative immersion and user-centered design, delivering experiences that are not only functional and engaging but also contextually relevant and culturally significant.

2.15 Summary

This chapter undertakes a comprehensive examination of the relevant literature in the domain of augmented reality. It covers a broad spectrum, delving into the fundamental principles of AR technology and exploring AAR systems that can dynamically respond to varying contexts or user needs. Additionally, the chapter scrutinizes the existing AR models and frameworks, shedding light on established approaches and theoretical foundations. The inclusion of this diverse literature is purposeful, as each topic is intricately connected to and contributes significantly to the overarching objective of this study, which is to enhance the understanding and application of augmented reality in a heritage context. By thoroughly analyzing the existing models and frameworks, this review highlights the core components that shape successful AR experiences, including adaptivity, and storytelling, . These elements are crucial in creating engaging, personalized, and contextually relevant augmented reality applications, particularly in the realm of cultural heritage preservation and learning.

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CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter outlines the phases of the methodology employed in this study. A well-structured methodology is crucial for ensuring that the research process is conducted systematically and effectively, guiding the study toward answering the research questions and achieving its objectives. The methodology applied for this study is the Design Science Research Methodology (DSRM) by Vaishnavi and Kuechler (2008); and (Vom Brocke et al., 2020). The DSRM was chosen as the overarching research paradigm for this thesis. This methodology is uniquely suited for studies in Information Systems (IS) and Computer Science, where the core objective is the development of an innovative solution (known as an artifact) intended to solve a significant real-world problem. In the context of this study, the artifact is the Adaptive Augmented Reality (AAR) Model with Storytelling Adaptation. The phases and activities to achieving objectives of this study is explain in this chapter.

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3.2 Research Design

This study adopts the Design Science Research Methodology (DSRM) to ensure a systematic and iterative process in developing and rigorously testing the proposed model. DSRM has long been recognised for its strong foundations and proven value in Information Systems research. It is widely accepted as a suitable framework for creating and evaluating innovative artifacts, including models, methods, constructs, and full system designs (Holopainen et al., 2020).

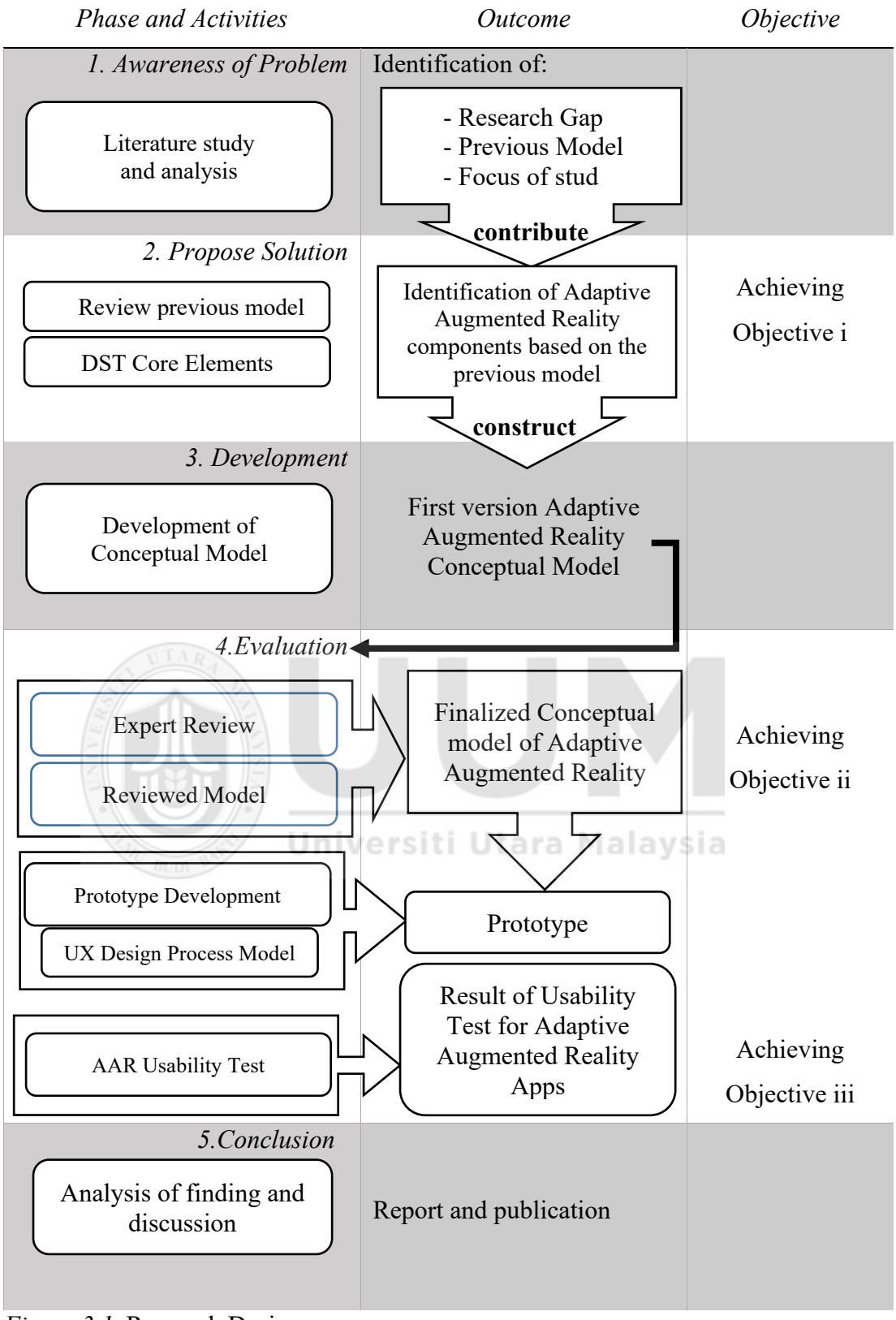


Figure 3.1. Research Design

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In this study, DSRM serves as the core methodological framework, following the structure outlined by Vaishnavi and Kuechler (2008) with appropriate adaptations. The research process is systematically organized into five key stages: (i) awareness of the problem, (ii) suggestion, (iii) development, (iv) evaluation, and (v) conclusion, as depicted in figure 3.1. The subsequent sections offer a comprehensive explanation of each stage, detailing their purpose and implementation within the context of this research

3.3 Phase 1: Awareness of Problem

The problem statement for this study emerged from insights gained through the literature review and a comparative examination of adaptive augmented reality components. A comprehensive review of existing studies and a content analysis were then conducted to determine the user, context, interaction, and environment models relevant to adaptive augmented reality. These analyses formed the preliminary stage of data collection, enabling the identification of research gaps and refining the study's direction.

3.4 Phase 2: Suggestion

Suggestion on the components were defined as a model of adaptive augmented reality in a local context. Reviews of the existing model and theoretical study were conducted to support the idea for constructing the model. This model provides details components of Adaptive Augmented Reality (AAR). In addition, the aspects of the user, local context, interaction and environment models were taken into considerations.

3.5 Phase 3: Development

In developing the Adaptive Augmented Reality (AAR) model, foundational principles were drawn from the existing conceptual model. This established model serves as the foundation for the AAR model's creation. Storytelling models, user models, context models, interaction models, and environment models are the key components in developing the AAR model. The combination of these elements is emphasising its holistic approach, which combines narrative elements, user considerations, contextual awareness, interactive functionalities, and environmental factors to create a robust and versatile augmented reality framework.

3.5.1 Existing Model Gathering

In this phase, a comprehensive review of articles related to Adaptive Augmented Reality was conducted with the primary objective of clarifying the definition of AAR within the existing academic literature. This process involved identifying and analyzing studies that describe the key components of AAR, including the concepts of adaptability in AR technologies and their application in immersive digital experiences. The primary objective was to seek a clear definition of Adaptive Augmented Reality (AAR), focusing on integrating adaptability and storytelling to enhance user interaction and experience. Thus, AAR was explored as form of storytelling by examining various models within this context. Through this process, a foundational understanding of AAR's unique role and potential in creating personalized, context-sensitive augmented reality applications was established.

3.5.2 Comparative analysis of the models

Existing conceptual models provided the underlying understanding of components critical to the Adaptive Augmented Reality (AAR). A comparison study was

performed to identify similarities and differences between these models, allowing for a more in-depth examination of their unique components. This comparative investigation included the systematic tabulation of significant components, allowing for a thorough side-by-side comparison. An extensive examination of relevant literature on Augmented Reality (AR) models, and the Digital Storytelling (DST) model was used to synthesise these comparative findings. By reviewing literature in these disciplines, insights about the distinguishing aspects of each model were gained, allowing for a better understanding of AAR.

Overview analysis of the reviewed models and frameworks for augmented reality, emphasizing the critical roles of adaptivity, storytelling, and user experience had been presents as Table 2.1 in Chapter Two. These models prioritize adaptivity to personalize AR experiences, ensuring they effectively respond to user needs and contextual factors, thereby significantly enhancing the overall user experience. Adaptivity in augmented reality is particularly advantageous for heritage preservation and cultural education, as it allows AR content to be customized according to the surrounding environment and user interactions, thereby enhancing user engagement and delivering a more immersive experience.

3.5.3 Identifying the core components of AAR model

The process in this phase began with an in-depth analysis of four existing adaptive augmented reality (AAR) models to identify the core components defining adaptivity in augmented reality. The models used are: A2R Museum Augmentation Model, Conceptual Framework for Adaptive Multimodal Interfaces in Mobile Augmented Reality, Conceptual Framework for Adaptive Augmented Reality, and i-ARA

Adaptive Augmented Reality as discussed in chapter two had provided a structured view of essential AAR components.

As previously discussed in chapter 2.4.5, the models collectively underscore a comprehensive approach to AAR that combines environmental context, user-specific data, and device capabilities to create responsive, personalized AR experiences. Each model, while distinct in focus, demonstrates the importance of context-awareness and user-centred design in adaptive augmented reality applications. Result of analyzing these four models the core components of Adaptive Augmented reality is defined as:

3.5.4 Development of conceptual model of AAR

The conceptual model was formed to represent the Adaptive Augmented Reality (AAR) model which formulated from the components of AAR and storytelling cores. Thus, the next step is to develop a conceptual model for an AAR application that incorporates storytelling elements to enhance user engagement and immersive experiences. The model's creation process follows a systematic pathway that begins with identifying core components and then moves through various steps of synthesis, expert review, refinement, and eventual development of a proof-of-concept. This ensures that the model accurately represents AAR principles while enriching the user experience through storytelling.

In the initial phase, when the essential components have been identified, the focus shifts to conceptualization. The objective here is to form a model that represents the AAR system inclusive of both AAR's core components and digital storytelling elements. Storytelling has been recognized as an influential tool in creating immersive

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media experiences, as it provides users with a narrative structure that enhances engagement and interactivity. By integrating digital storytelling elements into the AAR model, this framework aims to offer a richer, more compelling experience, as users are not only interacting with augmented elements but are also immersed in a narrative that drives meaningful engagement and connection to the content.

The process of developing the conceptual model comprises several key steps. First, there is the synthesis of components, which involves combining components both AAR and storytelling. This synthesis ensures that the model represents a unified structure, where storytelling components are purposefully integrated with AAR functionalities. This combination is crucial as it allows the model to achieve the definition of AAR while also employing storytelling techniques to sustain user interest and emotional engagement. Through synthesis, the model attempts to capture the unique synergy between technology and narrative, laying a solid foundation for a more engaging augmented reality experience.

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The next step involves an expert review, where specialists in AR, digital storytelling, or related fields evaluate the model. The purpose of this review is to verify that the model is comprehensive and representative of AAR principles, ensuring that it effectively integrates storytelling components to create a more immersive experience. Experts provide feedback on the model's strengths and areas for improvement, offering insights that can strengthen its theoretical foundation and practical applicability. Their input is essential in validating that the model not only aligns with the goals of AAR but can also serve as a robust framework for guiding future prototype development. This expert assessment is a crucial part of the iterative design process,

as it helps in identifying potential issues and refining the model to better suit user needs and technical requirements.

Following the review, the model undergoes refinement based on the feedback and comments from experts. This step is essential to ensure that any shortcomings identified during the review are addressed, and the model is optimized to meet the intended objectives. Refinement may involve adjustments to the storytelling elements, improvements in adaptive functionalities, or enhancements to ensure seamless integration between narrative and interactive components. By refining the model, the development process prioritizes accuracy, usability, and the potential for real-world application, increasing the model's relevance as a foundational guide for AAR systems.

Finally, after refinement, the next crucial phase involves building a proof-of-concept. This proof-of-concept serves as an early prototype and a demonstration of the model's feasibility in an operational context. The prototype's development follows the User Experience (UX) process models to create a tangible version of the conceptual framework. By moving the model from concept to a practical application, developers can directly observe its real-world performance, assess user engagement, and identify areas for improvement. Crucially, the proof-of-concept provides the necessary environment to test the model's core features adaptability and storytelling in real-time, allowing for a hands-on evaluation of how effectively the framework creates immersive, engaging experiences that respond dynamically to user interactions can create immersive, engaging experiences that respond to user interactions.

In summary, this approach to developing an AAR model integrates storytelling as a component to enhance user experience, following a rigorous process of synthesis,

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review, refinement, and prototyping. Through this comprehensive process, the model aims to represent a balanced blend of adaptive functionality and narrative-driven engagement, offering a structured yet flexible foundation for creating meaningful AAR applications.

3.6 Phase 4: Evaluation

The evaluation phase aimed to assess the proposed adaptive augmented reality (AAR) model through two distinct processes: expert review and usability testing. This phase encompassed two key activities: expert review of the model and usability testing of the AAR application. During the expert review process, as detailed in the previous chapter, three specialists with expertise in augmented reality (AR), human-computer interaction (HCI), and multimedia validated the initial model. Based on their feedback, refinements were made to enhance the model, which then served as the foundation for the development of the AAR application. The refined application prototype was subsequently provided to users for field testing, accompanied by a questionnaire designed to evaluate its usability. The usability questionnaire was developed by adapting an established usability assessment instrument from Handheld Augmented Reality Usability Scale (HARUS) developed by Santos et al. (2015) and the Augmented Reality Immersion (ARI) questionnaire by Georgiou and Kyza (2017). The selection of expert review and usability evaluation for Phase 4 was a deliberate strategic choice to ensure the rigor and comprehensiveness of the Adaptive Augmented Reality (AAR) model's validation. This two approach was necessary to address the dual nature of the research problem: the theoretical construction of the model and its practical implementation as an application.

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3.6.1 Instrument Development

In this phase a comprehensive questionnaire for evaluating the usability of an Adaptive Augmented Reality (AAR) application is produced. The processes began with the careful selection and development of questionnaire items. The development of a comprehensive questionnaire for evaluating the usability of an Adaptive Augmented Reality (AAR) application was guided by two primary sources: Santos et al. (2015) and Georgiou and Kyza (2017). These references provided validated items for usability testing in augmented reality contexts. The constructs addressed in the questionnaire include comprehensibility, manipulability, engagement, engrossment, and total immersion, which are critical for assessing the usability of the AAR application effectively. These items are adapted to align with the specific objectives and functionalities of the AAR application (as depicted in Table 3.1).

Table 3.1 Usability testing Questionnaire

Items	**Questions**
Comprehensibility Santos et al. (2015)	Q1: I think interacting with this application requires significant mental effort.
	Q2: I felt that the amount of information displayed on the screen was appropriate.
	Q3: I thought the information displayed on the screen was difficult to read.
	Q4: I felt the information display was responding quickly enough.
	Q5: I thought the information displayed on the screen was confusing.
	Q6: I found the words and symbols on the screen easy to read.
	Q7: I felt the display flickered too much.

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	Q8: I thought the information displayed on the screen was consistent.
Manipulability Santos et al. (2015)	Q1: I think that interacting with this AR application requires a lot of body muscle effort. Q2: I felt that using the AR application was comfortable for my arms and hands. Q3: I found the device difficult to hold while operating the AR application. Q4: I felt that my arm or hand became tired after using the AR application. Q5: I think the AR application is easy to control. Q6: I felt that I was losing grip and dropping the device at some point. Q7: I think the operation of this AR application is simple and uncomplicated
Engagement Georgiou and Kyza (2017)	Q1: I liked the activity because it was novel Q2: I liked the type of the activity Q3: I wanted to spend the time to complete the activity successfully Q4: I wanted to spend time to participate in the activity Q5: It was easy for me to use the AR application Q6: I found the AR application confusing* Q7: The AR application was unnecessarily complex* Q8: I did not have difficulties in controlling the AR application
Engrossment Georgiou and Kyza (2017)	Q1: I was curious about how the activity would progress Q2: I was often excited since I felt being part of the activity Q3: I often felt suspense by the activity Q4: If interrupted, I looked forward to returning to the activity

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	Q5: Everyday thoughts and concerns faded out during the activity Q6: I was more focused on the activity rather than on any external distraction
Total immersion Georgiou and Kyza (2017)	Q1: The activity felt so authentic that it made me think that the virtual characters/objects existed for real. Q2: I felt that what I was experiencing was something real, instead of a fictional activity. Q3: I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly. Q4: I was so involved, that I felt that my actions could affect the activity. Q5: I didn't have any irrelevant thoughts or external distractions during the activity. Q6: The activity became the unique and only thought occupying my mind. Q7: I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity.

The constructs were selected from two established instruments, HARUS (Santos et al., 2015) and ARI (Georgiou & Kyza, 2017), because they provide validated measures of usability in augmented reality contexts and are widely applied in assessing usability. These constructs ensure that both functional interaction and immersive experience are captured in the evaluation. Table 3.2 presents the mapping between usability constructs and the four components of the AAR model: User Personalization (UP), Digital Storytelling (DST), Environment (EV), and Other Components (OC). Each construct represents a user-centered criterion for evaluation, while the model components represent the features of AAR being assessed. This mapping illustrates how established usability constructs can be applied to validate the AAR model.

Table 3.2 Mapping of Usability Constructs and AAR Model Components

USABILITY CONSTRUCTS	AAR COMPONENTS
Comprehensibility Definition: How easily users can understand the content, instructions, and interface without confusion.	Environment (EV) Definition: The medium and context of AR content, including visuals, layout, and cues that support understanding.
Manipulability Definition: How easily users can control and interact with AR objects, reflecting responsiveness and ease of use.	Other Components (OC) Definition: Devices, sensors, and services that enable smooth interaction.
Engagement Definition: The ability of AR to capture and hold users' interest through interactive and relevant content.	Environment (EV) Definition: EV provides sensory richness, User Personalization (UP) Definition: UP adapts content to user needs and preferences, sustaining motivation.
Engrossment Definition: The level of user absorption and emotional involvement in the AR experience.	Digital Storytelling (DST) Definition: DST through Narrative and cultural elements that deepen emotional connection.
Total Immersion Definition: The state where users feel fully present in AR, often losing awareness of the real world.	Digital Storytelling (DST) Definition: DST provides narrative flow, while User Personalization (UP) Definition: UP ensures content feels personally relevant, enhancing presence.

i. Comprehensibility and Environment (EV)

Firstly, the construct comprehensibility is closely associated with the environment (EV). It refers to how easily users can understand the AR application's content, instructions, and functions without confusion. Previous studies in AR usability (Santos et al., 2014) highlight the importance of clarity in reducing cognitive load. In the AAR model, the environment supports comprehension through its visual presentation,

spatial layout, and contextual cues. When the environment is well structured, users can quickly make sense of the information presented, thereby enhancing usability. However, a poorly designed environment risks overwhelming users and diminishing their ability to comprehend the system effectively.

ii. Manipulability and Other Components (OC)

Manipulability is strongly linked to other components (OC), which include the devices, sensors, and services that enable user interaction. This construct measures how easily users can control and manipulate AR elements. Research in HCI and AR interaction (Georgiou & Kyza, 2017) underscores the importance of responsiveness, accuracy, and intuitive input methods. In practice, the effectiveness of gesture recognition, motion tracking, or touch interfaces depends on the reliability of these components. When devices and sensors operate smoothly, manipulation feels natural, leading to higher perceived usability. Conversely, poor responsiveness or technical limitations reduce manipulability and cause user frustration.

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iii. Engagement, Environment (EV), and User Personalization (UP)

The construct engagement connects to both the environment (EV) and user personalization (UP). Engagement reflects the system's ability to capture and sustain user interest. The environment contributes through immersive settings, sensory richness, and contextual relevance (Santos et al., 2014). Meanwhile, personalization strengthens engagement by tailoring content to individual user profiles, needs, or preferences. In adaptive AR applications, this means that users are not only attracted by the visual and sensory qualities of the environment but also motivated to stay

involved because the content feels personally relevant. This dual role ensures that engagement is both broadly stimulating and individually meaningful.

iv. Engrossment and Digital Storytelling (DST)

Engrossment is supported by digital storytelling (DST). It refers to the depth of psychological absorption and emotional involvement in the AR experience. Storytelling provides narrative flow, cultural or heritage themes, and character-driven content, which give meaning beyond functional interaction (Georgiou & Kyza, 2017). Within the AAR model, storytelling situates users inside coherent and adaptive narratives, fostering emotional resonance and stronger connection to the content. This process transforms AR from a technical tool into an immersive cultural or educational journey, elevating user involvement through meaningful narrative engagement.

v. Total Immersion, Digital Storytelling (DST), and User Personalization (UP)

Total immersion represents the highest level of presence in AR, where users feel fully absorbed in the virtual environment and may lose awareness of the real world. This state is influenced by both digital storytelling (DST) and user personalization (UP). Storytelling provides the narrative continuity and adaptive flow that sustain immersion (Slater et al., 1994). Personalization further enhances this by ensuring that the experience feels tailored to the individual, reinforcing presence and realism. Together, DST and UP blur the boundaries between the real and virtual, allowing users to perceive AR as a seamless alternate reality.

By aligning constructs with components in this way, the study ensures that the AAR framework is validated not only conceptually but also through measurable usability outcomes. Usability testing was adopted because the AAR model is designed to

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improve subjective user experiences, specifically comprehensibility, engagement, and immersion. As shown in Table 3.3, the model's technical components are structured to evoke these psychological responses. Since these outcomes depend on individual perception rather than mechanical system performance, self-reporting measures provide the most meaningful form of validation. The adaptive effectiveness is therefore assessed through the extent to which users indicate feeling engaged and immersed, demonstrating that the personalized content successfully addressed their needs.

Based on the identified constructs, the questionnaire developed was divided into two parts. Part A focused on collecting demographic information about the respondents, including their gender, age, experience with augmented reality, and the frequency of their daily use of mobile devices. This demographic data provides important context for interpreting usability feedback and understanding the user base. Part B of the questionnaire focused on usability questions designed to evaluate the Adaptive Augmented Reality (AAR) application based on the five constructs: comprehensibility, manipulability, engagement, engrossment, and total immersion.

The comprehensibility construct assessed the clarity and ease with which users could understand the information presented in the application, ensuring that content was accessible and straightforward. The manipulability construct evaluated the physical ease of interacting with the application, such as the effort required for device handling and overall comfort during use. Engagement focused on measuring the level of interest and involvement users experienced while interacting with the application, reflecting its ability to captivate and retain user attention. The engrossment construct captured

the degree of user absorption, examining how focused and immersed users were in the activities facilitated by the AAR application. Lastly, the total immersion construct assessed the extent to which users felt fully immersed in the augmented reality experience, indicating the application's ability to provide an authentic and seamless virtual environment.

Each usability question in part b was designed using a five-point Likert scale format which the scale anchors were defined as: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree (refer to Appendix A). The 5-points Likert scale was adopted due to its wide acceptance and established validity in measuring AR usability and immersion. This selection aligns the current instrument with proven methodological practice, as demonstrated by leading scales like the Handheld Augmented Reality Usability Scale (HARUS) (Santos et al., 2015) and the Augmented Reality Immersion (ARI) questionnaire (Georgiou and Kyza, 2017), both of which successfully utilize the 5-points format. Similarly, the System Usability Scale (SUS), one of the most widely used usability instruments, utilizes the same format and has consistently demonstrated strong reliability and validity across diverse contexts (Brooke, 1996; Lewis, 2018). The 5-point scale offers a balance of simplicity, sensitivity, and discrimination, allowing subjective perceptions to be converted into quantifiable data for statistical analysis (Chyung et al., 2017) making it the most suitable choice for usability and AR evaluation studies. The 5-points Likert scale enabling respondent to rate their level of agreement or perception on various aspects of usability. This format not only ensured consistency in responses but also provided quantifiable data for a comprehensive analysis.

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3.6.2 Content and Face Validation

The validity test is essential for evaluating the accuracy and appropriateness of a research instrument. To ensure the instrument accurately measures its intended constructs, validity testing was conducted. This process involved assessing the instrument's suitability for the study through content and face validity tests. These validation procedures were performed to establish the integrity of the measures (Sekaran & Bougie, 2016).

To ensure the rigor and credibility of the instrument used for usability evaluation, experts were selected through purposive sampling guided by specific criteria. Each expert was required to hold at least a doctoral degree (PhD) in a relevant discipline. Their fields of expertise had to align closely with the study's core research domains, namely Human-Computer Interaction (HCI), Multimedia, or Information and Communication Technology (ICT). In addition, a minimum of ten years of professional experience in their respective areas was required to ensure substantial domain knowledge and practical insight. These criteria collectively ensured that the expert panel possessed the necessary academic depth and professional experience to critically evaluate the conceptual soundness, usability aspects, and technical implementation of the AAR model and its associated instrument.

The initial draft of the questionnaire underwent a comprehensive content and face validation process carried out by three experts with extensive academic and professional backgrounds in Human-Computer Interaction (HCI), Multimedia, and Information and Communication Technology (ICT). The involvement of three experts is methodologically justified, as literature suggests that a minimum of three experts is

sufficient to establish reliability while reducing individual bias and ensuring a diversity of perspectives (Lynn, 1986; Rubio et al., 2003). The profiles of the experts involved in this validation process are detailed in table 3.3.

Table 3.3 List of Experts for Instrument Validation

Experts	Gender	Education	Fields of Expertise	Experience (Years)
Expert 1	Female	PhD.	HCI, Multimedia	20
Expert 2	Male	PhD.	ICT	20
Expert 3	Male	PhD.	Multimedia	10

All three experts involved in the instrument validation process have over 10 years of experience in their respective fields, ensuring a high level of expertise and credibility in the validation process. Their role is to assess each question for relevance in measuring usability.

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All three experts agreed that the instrument was conceptually sound and suitable for evaluating the usability of Adaptive Augmented Reality (AAR) in a heritage context. The questionnaire items were revised according to expert feedback to make them clearer, more accurate, and better aligned with their intended constructs. While expert 1, 2 and 3 recommended several refinements to strengthen clarity, construct coverage, and wording precision. Specifically, some changes were made based on expert 3 recommendations. For item 6 focus was expanded from reading symbols to understanding their meaning, ensuring users interpret icons correctly rather than just seeing them clearly. For item 13 and 15, the wording was refined to emphasize how easily users can adjust the device position and control virtual objects, reflecting real

AR interactions. Item 19 was adjusted to measure sustained interest in the activity, while item 20 captures the user's sense of happiness and engagement during use. In item 24, the term "*tergamam*" for Bahasa Malaysia version was replaced with "*terpesona"* to give a clearer and more positive emotional tone. Lastly, item 29 was rewritten to highlight a stronger sense of believability and deep immersion instead of focusing only on realism.

These revisions make the items simpler, clearer, and more relevant while keeping their original structure and tone. Each construct: Comprehensibility, Manipulability, Engagement, Engrossment, and Total Immersion is now more distinct and accurately represented, resulting in a more reliable and effective instrument for assessing user experience in Adaptive Augmented Reality for heritage applications. The updated questionnaire in table 3.4 were used for pilot testing with a small group of participants who represent the target user base of the AAR application.

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Table 3.4 The Validated AAR Usability constructs and questions

Constructs	**Questions**
Comprehensibility Kebolehfahaman	1 Saya berpendapat bahawa berinteraksi dengan aplikasi ini memerlukan banyak usaha mental *I think that interacting with this application requires a lot of mental effort*
	2 Saya berpendapat jumlah maklumat yang dipaparkan di skrin adalah bersesuaian *I thought the amount of information displayed on screen was appropriate*
	3 Saya berpendapat bahawa maklumat yang dipaparkan di skrin sukar dibaca

		I thought that the information displayed on screen was difficult to read
	4	Saya merasakan respon paparan maklumat cukup pantas *I felt that the information display was responding fast enough*
	5	Saya berpendapat bahawa maklumat yang dipaparkan di skrin mengelirukan *I thought that the information displayed on screen was confusing*
	6	Saya berpendapat simbol dan ikon pada skrin mudah difahami. *I thought the symbols and icons on the screen were easy to understand.*
	7	Saya merasakan bahawa paparan terlalu banyak kelipan. *I felt that the display was flickering too much*
	8	Saya berpendapat bahawa maklumat yang dipaparkan di skrin adalah konsisten *I thought that the information displayed on screen was consistent*
Manipulability Kebolehkendalian	9	Saya berpendapat bahawa berinteraksi dengan aplikasi AR ini memerlukan banyak usaha otot badan *I think that interacting with this AR application requires a lot of body muscle effort*
	10	Saya merasakan penggunaan AR adalah selesa untuk tangan saya *I felt that using the AR application was comfortable for my arms and hands*

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	11	Saya mendapati peranti sukar dipegang semasa mengendalikan aplikasi AR *I found the device difficult to hold while operating the AR application*
	12	Saya merasakan lengan atau tangan saya menjadi letih setelah menggunakan aplikasi AR *I felt that my arm or hand became tired after using the AR application*
	13	Saya merasakan bahawa pelarasan posisi atau orientasi peranti untuk melihat objek AR adalah mudah. *I felt that the adjusting the device position or orientation to view the AR object was easy.*
	14	Saya merasakan bahawa saya kehilangan cengkaman dan menjatuhkan peranti pada satu ketika *I felt that I was losing grip and dropping the device at some point*
	15	Saya berpendapat kawalan objek maya menggunakan pergerakan tangan adalah mudah. *I thought controlling the virtual objects using hand movements was easy.*
Engagement Keterlibatan	16	Saya suka aktiviti itu kerana ia adalah baharu *I liked the activity because it was novel*
	17	Saya suka jenis aktiviti tersebut *I liked the type of the activity*
	18	Saya ingin meluangkan masa untuk menyelesaikan aktiviti dengan jayanya *I wanted to spend the time to complete the activity successfully*

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	19	Saya ingin terus menyertai aktiviti ini kerana ia menarik. *I wanted to continue participating in this activity because it was interesting.*
	20	Saya berasa gembira dan terlibat sepenuhnya semasa menggunakan aplikasi AR. *I felt happy and fully engaged while using the AR application.*
	21	Saya mendapati aplikasi AR mengelirukan *I found the AR application confusing*
Engrossment Penghayatan	22	Saya ingin tahu bagaimana penceritaan itu akan berlangsung *I was curious about how the story would progress*
	23	Saya sering teruja kerana saya merasa menjadi sebahagian daripada penceritaan tersebut *I was often excited since I felt as being part of the story*
	24	Saya sering berasa terpesona dengan penceritaan tersebut. *I often felt fascinated by the storytelling.*
	25	Sekiranya terganggu, saya tidak sabar untuk kembali ke penceritaan *If interrupted, I looked forward to returning to the story*
	26	Fikiran dan kebimbangan harian kurang dirasai semasa penceritaan *Everyday thoughts and concerns faded out during the storytelling*
	27	Saya lebih fokus pada penceritaan dan bukannya pada gangguan luaran

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		I was more focused on the story rather on any external distraction
Total immersion Keasyikan Keseluruhan	28	Penceritaan tersebut terasa sangat asli/tulen sehingga membuat saya berfikir bahawa watak / objek maya wujud dengan nyata *The story felt so authentic that it made me think that the virtual characters/objects existed for real*
	29	Saya merasakan bahawa apa yang saya alami terasa benar-benar mengasyikkan dan meyakinkan. *I felt that what I experienced felt completely immersive and believable.*
	30	Saya begitu terlibat dalam penceritaan tersebut, sehingga dalam beberapa kes saya mahu berinteraksi dengan watak / objek maya secara langsung *I was so involved in the story, that in some cases I wanted to interact with the virtual characters/objects directly*
	31	Saya begitu terlibat, dan merasakan tindakan saya boleh mempengaruhi penceritaan tersebut *I so was involved, that I felt that my actions could affect the story*

3.6.3 Pilot Test

A pilot study was carried out among a limited group of participants, primarily to assess the suitability of approaches intended for larger-scale studies. This preliminary investigation aimed to test the validity and reliability of the construct, identifying any potential limitations for the main study (Hair et al., 2019; Sekaran & Bougie, 2016). Conducting a pilot study is essential before embarking on extensive data collection for

analysis, following a procedure akin to that employed in larger-scale studies. In this case, the pilot testing involved 97 university students specializing in heritage studies at Universiti Malaysia Kelantan, aligning with the stipulations outlined by (Coakes et al., 2008) which requires a minimum sample size of at least 30 respondents. The purposive sampling method was employed for participant selection, consistent with (Hair et al., 2019) recommendation that a sample size of 50 is necessary for critical value in factor analysis.

Students of 97 had been gathered in the classroom for be brief introduction about the application and students were asked to install the application for trial. After they used the application for at least 10 minutes, they were provided a set of the questionnaires. The following sections discuss factor analysis and reliability analysis conducted after the pilot test to test the questionnaire.

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3.6.4 Data Preparation and Recoding

To ensure directional consistency and accurate interpretation of the results, all negatively phrased (reverse-scored) items within the questionnaire were recoded prior to conducting statistical analysis. Utilizing the five-point Likert scale, the recoding procedure involved converting the original scores such that 1 (Strongly Disagree) was converted to 5 (Strongly Agree), 2 to 4, 4 to 2, and 5 to 1. The neutral response of 3 remained unchanged.

All subsequent analyses, including Exploratory Factor Analysis, reliability testing, and descriptive statistics, were performed on these recoded values, thus ensuring that a higher mean score consistently indicated a more favourable user perception across all

measured variables. Specifically, the items identified as reverse-scored across the constructs (e.g., COMPRE2, MANI1, MANI2, MANI3, and ENGG5) underwent a mathematical transformation.

3.6.5 Factor Analysis

Factor analysis was conducted to examine the construct validity and interpret the self-report questionnaire, following the methodologies outlined by Bryant et al. (1999) and Ugulu (2013). This statistical technique is designed to analyze variability among observed variables, thereby identifying potential latent factors. The analysis sought to validate the dimensions of the operationally defined constructs and determine the most appropriate items for each factor, as guided by the recommendations of Sekaran and Bougie (2016). The study utilized the exploratory factor analysis (EFA) method, aiming to unveil the factor structure and determine if the designated data aligns with expectations. In essence, EFA seeks to elucidate the fundamental structure of variables based on the rotated component matrix. The acceptance of each item was based on three key test indicators: the Kaiser-Meyer-Olkin (KMO) test for sampling adequacy, the Bartlett's test of sphericity, and factor loadings.

To ensure a rigorous and statistically defensible instrument structure, considering the study's sample size of N=97, a conservative factor loading threshold was applied. The decision was made to set the minimum factor loading upward to ≥ 0.60 This criterion is specifically informed by the guidelines of Hair et al. (2019) for practical significance, as a loading of 0.60 is confirmed to achieve practical significance with a sample size of only N=85. Because the study's N=97 exceeds this minimum requirement, 0.60 was deemed the appropriate and most robust criterion for item and factor retention. In

accordance with the guidelines provided by Pallant (2016) and Hair et al. (2019) the factor analysis adhered to these three fundamental rules:

Rule 1: KMO value must be ≥ 0.5 and Bartlett's test of sphericity, the significant value of p ≤ .05

Rule 2: MSA for the items ≥ 0.5

Rule 3: First component of Component Matrix ≥ 0.60

According to (Hair et al., 2019), these guidelines are applicable when the sample size reaches 100 or more, with an emphasis on practical significance rather than strict statistical criteria. Table 3.5 outlines the recommended sample size guidelines for each factor loading factor deemed significant, according to (Hair et al., 2019). It is advised to adhere to these guidelines right from the initiation of the factor-loading interpretation.

Table 3.5 Guidelines for Identifying Factor Loading Based on Sample Size

Factor loading	Sample size needed
0.30	350
0.35	250
0.40	200
0.45	150
0.50	120
0.55	100
0.60	85
0.65	70
0.70	60
0.75	50

Source: Hair et al (2013, p.115)

This study evaluates the usability instrument adapted from Santos et al. (2015) and Georgiou and Kyza (2017) to ensure its suitability for assessing the usability of the AAR prototype. While the items were derived from established frameworks, their specific validity for this context had not been confirmed. To address this, a series of

analyses were conducted, including the KMO and Bartlett's test, the Measure of Sampling Adequacy (MSA), and an evaluation of the component matrix. These analyses confirm that the instrument is valid and effectively measures the intended usability constructs. The detailed findings are presented in the following sections.

3.6.5.1 Factor Analysis Results for Comprehensibility

The construct validity of the Comprehensibility scale was first assessed using Exploratory Factor Analysis (EFA). The following tables present the results of the KMO, Bartlett's test, and item-level analyses conducted to verify the factorability and robustness of the items.

Rule 1: KMO test and Bartlett's test

Table 3.6 KMO and Bartlett's Test for Comprehensibility

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.734
Bartlett's Test of Sphericity	Approx. Chi-Square	110.363
	df	28
	Sig.	.000

Table 3.6 depicts KMO and Bartlett's tests. It can be noticed that KMO measures of sampling adequacy value are 0.734 ($p \geq 0.50$) and Bartlett's Test of Sphericity is 0.000 ($p \leq .05$)

Rule 2: MSA test

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Table 3.7 MSA for each item of Comprehensibility

No.	Items for Comprehensibility	p-value
1	COMPRE1	.721[a]
2	COMPRE2	.765[a]
3	COMPRE3	.733[a]
4	COMPRE4	.695[a]
5	COMPRE5	.759[a]
6	COMPRE6	.697[a]
7	COMPRE7	.715[a]
8	COMPRE8	.766[a]

a. Measures of Sampling Adequacy (MSA)

Table 3.7 performed the MSA test for each item of enjoyment and the p-value for all the items are more than 0.5. The p- values in the table met rule 2.

Rule 3: Component Matrix

Table 3.8 Component Matrix[a] for Comprehensibility

Component Matrix[a]	
	Component 1
COMPRE1	.560
COMPRE2	.646
COMPRE3	.584
COMPRE4	.253
COMPRE5	.620
COMPRE6	.636
COMPRE7	.503
COMPRE8	.608

Extraction Method: Principal Component Analysis.

The value for the first component of the component matrix should be equal or greater than 0.60. Table 3.8 depicts that all the items are more than 0.6 which means all the items are understandable to the user, except item 1 is 0.560, item 3 is 0.584, item 4 is 0.253 and item 7 is 0.503. These items value 0.6 are indicate may not fit well with the other items in the component or is less understandable to users. Items 1, 3, 4 and 7 were subsequently removed due to its low loading.

3.6.5.2 Factor Analysis Results for Manipulability

The factory analysis of the construct Manipulability was assessed using Exploratory Factor Analysis (EFA). The following tables present the results of the KMO, Bartlett's test, and item-level analyses conducted to verify the factorability and robustness of the items.

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Rule 1: KMO test and Bartlett's test

Table 3.9 KMO and Bartlett's Test for Manipulability

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.738
Bartlett's Test of Sphericity	Approx. Chi-Square	109.912
	df	21
	Sig.	.000

Table 3.9 depicts KMO and Bartlett's tests. It can be noticed that KMO measures of sampling adequacy value are 0.738 ($p \geq 0.50$) and Bartlett's Test of Sphericity is 0.000 ($p \leq .05$)

Rule 2: MSA test

Table 3.10 MSA for each item of Manipulability

No.	Items for Comprehensibility	p-value
1	MANI1	.833[a]
2	MANI2	.816[a]
3	MANI3	.720[a]
4	MANI4	.753[a]
5	MANI5	.628[a]
6	MANI6	.753[a]
7	MANI7	.697[a]

a. Measures of Sampling Adequacy (MSA)

Table 3.10 performed the MSA test for each item of enjoyment and the p-value for all the items are more than 0.50. The p- values in the table met rule 2.

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Rule 3: Component Matrix

Table 3.11 Component Matrix[a] for Manipulability

Component Matrix[a]	
	Component 1
MANI1	.549
MANI2	.599
MANI3	.689
MANI4	.689
MANI5	.474
MANI6	.634
MANI7	.562

Extraction Method: Principal Component Analysis.

The value for the first component of the component matrix should be equal or greater than 0.60. Table 3.11 depicts that all the items are more than 0.60 which means all the items are understandable to the user. Except for item 1 is 0.549, item 2 is 0.599, item 5 is 0.474 and item 7 is 0.562 thus items 1, 2, 5, and 7 were removed. This indicate these 4 items may not fit well with the other items in the component, Item 1, 2, 5 and 7 been removed from this factor.

3.6.5.3 Factor Analysis Results for Engagement

These are the results of the KMO, Bartlett's test, and item-factor analysis conducted to verify the robustness of the items for the construct engagement. It was presented in next section.

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Rule 1: KMO test and Bartlett's test

Table 3.12. KMO and Bartlett's Test for Engagement

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.718
Bartlett's Test of Sphericity	Approx. Chi-Square	133.400
	df	15
	Sig.	.000

Table 3.12 depicts KMO and Bartlett's tests. It can be noticed that KMO measures of sampling adequacy value are 0.718 ($p \geq 0.50$) and Bartlett's Test of Sphericity is 0.000 ($p \leq .05$)

Rule 2: MSA test

Table 3.13 MSA for each item of Engagement

No.	Items for Comprehensibility	p-value
1	ENGG1	.694[a]
2	ENGG2	.683[a]
3	ENGG3	.717[a]
4	ENGG4	.673[a]
5	ENGG5	.808[a]
6	ENGG6	.776[a]

a. Measures of Sampling Adequacy (MSA)

Table 3.13 performed the MSA test for each item of enjoyment and the p-value for all the items are more than 0.5. The p- values in the table met rule 2. The rule 3 is presented next.

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Rule 3: Component Matrix

Table 3.14 Component Matrix[a] for Engagement

Component Matrix[a]	
	Component
	1
ENGG1	.757
ENGG2	.749
ENGG3	.526
ENGG4	.666
ENGG5	.710
ENGG6	.615

Extraction Method: Principal Component Analysis.

Table 3.14 depicts that all the items are more than 0.60 which means all the items are understandable to the user. Except for item 3 is 0.526, thus item 3 was removed. This

indicate item 3 may not fit well with the other items in the component and been removed from this factor.

3.6.5.4 Factor Analysis Results for Engrossment

This section presents the results of the KMO, Bartlett's test, and item-level analyses conducted to verify the factorability and robustness of the items for engrossment.

Rule 1: KMO test and Bartlett's test

Table 3.15 KMO and Bartlett's Test for Engrossment

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.620
Bartlett's Test of Sphericity	Approx. Chi-Square	81.707
	df	15
	Sig.	.000

Table 3.15 depicts KMO and Bartlett's tests. It can be noticed that KMO measures of sampling adequacy value are 0.620 ($p \geq 0.50$) and Bartlett's Test of Sphericity is 0.000 ($p \leq .05$)

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Rule 2: MSA test

Table 3.16 MSA for each item of Engrossment

No.	Items for Comprehensibility	p-value
1	ENGRSS1	.568[a]
2	ENGRSS2	.548[a]
3	ENGRSS3	.537[a]
4	ENGRSS4	.720[a]
5	ENGRSS5	.638[a]
6	ENGRSS6	.700[a]

a. Measures of Sampling Adequacy (MSA)

Table 3.16 performed the MSA test for each item of enjoyment and the p-value for all the items are more than 0.5. The p-values in the table met rule 2.

Rule 3: Component Matrix

Table 3.17 Component Matrix[a] for Engrossment

Component Matrix[a]	
	Component
	1
ENGRSS1	.613
ENGRSS2	.632
ENGRSS3	.393
ENGRSS4	.679
ENGRSS5	.534
ENGRSS6	.696

Extraction Method: Principal Component Analysis.

Table 3.17 depicts that all the items that are more than 0.60 which means all the items are understandable to the user. Except for item 3 is 0.393 and item 5 is 0.534. This indicate items 3 and 5 may not fit well with the other items in the component, Items 3 and 5 been removed from this factor.

3.6.5.5 Factor Analysis Results for Total Immersion

Finally, following tables present the results of the KMO, Bartlett's test, and item-level analyses conducted to verify the factorability and robustness of the items for total immersion.

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Rule 1: KMO test and Bartlett's test

Table 3.18. KMO and Bartlett's Test for Total Immersion

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.652
Bartlett's Test of Sphericity	Approx. Chi-Square	106.934
	df	6
	Sig.	.000

Table 3.18 depicts KMO and Bartlett's tests. It can be noticed that KMO measures of sampling adequacy value are 0.652 ($p \geq 0.50$) and Bartlett's Test of Sphericity is 0.000 ($p \leq .05$).

Rule 2: MSA test

Table 3.19 MSA for each item of Total immersion

No.	Items for Comprehensibility	p-value
1	IMMER1	.669[a]
2	IMMER2	.683[a]
3	IMMER3	.647[a]
4	IMMER4	.625[a]

a. Measures of Sampling Adequacy (MSA)

Table 3.19 performed the MSA test for each item of enjoyment and the p-value for all the items are more than 0.5. The p- values in the table met rule 2.

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Rule 3: Component Matrix

Table 3.20 Component Matrix[a] for Total immersion

Component Matrix[a]	
	Component
	1
IMMER2	.646
IMMER3	.779
IMMER1	.778
IMMER4	.818

Extraction Method: Principal Component Analysis.

The value for the first component of the component matrix which should be equal or greater than 0.60. Table 3.29 depicts that all the items that are more than 0.60 which means all the items are understandable to the user.

As shown in the table 3.21 a total of 10 items were removed across the five constructs due to low factor loadings (Rule 3: Component Matrix loading < 0.60). Specifically, for Comprehensibility, four items were removed (COMPRE1, COMPRE3, COMPRE4, and COMPRE7). The Manipulability construct saw the removal of four items (MANI1, MANI2, MANI5, and MANI7). Engagement had one item removed (ENGG3). Finally, Engrossment required the removal of two items (ENGRSS3 and ENGRSS5). The construct Total Immersion retained all its items, as their factor loadings were all above the 0.60 threshold.

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Table 3.21 Remaining Items After Exploratory Factor Analysis

Construct	Initial Number of Items	Items Removed (Loading <0.60)	Items Remaining	Final Item Count
Comprehensibility	8	COMPRE1, COMPRE3, COMPRE4, COMPRE7	COMPRE2, COMPRE5, COMPRE6, COMPRE8	4
Manipulability	7	MANI1, MANI2, MANI5, MANI7	MANI3, MANI4, MANI6	3
Engagement	6	ENGG3	ENGG1, ENGG2, ENGG4, ENGG5, ENGG6	5
Engrossment	6	ENGRSS3, ENGRSS5	ENGRSS1, ENGRSS2, ENGRSS4, ENGRSS6	4
Total Immersion	4	None	IMMER1, IMMER2, IMMER3, IMMER4	4
Total Items	31	11	20	20

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This item reduction process resulted in a more robust and parsimonious measurement model, with the total number of items across all scales reduced from 31 to 20 for use in subsequent analyses.

3.6.6 Reliability Analysis

Bordens and Abbott (2014) assert that an instrument is deemed satisfactory when its Cronbach's Alpha exceeds 0.8. However, if the instrument is in its preliminary stage, a value exceeding 0.6 is still considered acceptable (Moss et al., 1998). In adherence to this study, the criterion for the minimum acceptable Cronbach's Alpha value is set

at 0.7 (Sekaran & Bougie, 2016). The calculation of Cronbach's Alpha value was conducted using SPSS software to establish the correlation among multiple measurements within a dimension.

The pilot test is essential for reliability analysis, as it helps evaluate the consistency of the questionnaire. In this study, 97 Heritage Studies students from Universiti Malaysia Kelantan participated. Their responses were used to calculate reliability metrics like Cronbach's Alpha, which checks if the items are consistent. The pilot test also helped identify and fix any issues, ensuring the questionnaire was reliable and effective for the main survey.

Table 3.22 Reliability Statistics

CONSTRUCTS	CRONBACH'S ALPHA	N OF ITEMS
COMPREHENSIBILITY	.643	4
MANIPULABILITY	.690	3
ENGAGEMENT	.751	5
ENGROSSMENT	.618	4
TOTAL IMMERSION	.752	4

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The Reliability Analysis was conducted on the purified scales resulting from the EFA to assess their internal consistency. as presented in Table 3.22 are adhering to the established criterion of a minimum Cronbach's Alpha of 0.7, the results show that two constructs, Engagement (0.751) and Total Immersion (0.752), demonstrated high internal consistency, successfully exceeding this stringent threshold. The remaining three constructs: Comprehensibility (0.643), Manipulability (0.690), and Engrossment (0.618) showed reliability scores marginally below the 0.7 target. However, as Manipulability was extremely close to 0.7, and all three values exceeded the 0.6

benchmark, they are still considered conditionally acceptable, thus confirming the adequacy of all five refined scales for use in subsequent testing.

Following the refinement process during the Exploratory Factor Analysis (EFA), items with factor loadings below the threshold of 0.60 were removed from the analysis as it did not significantly contribute to the reliability or interpretability of the component. The finalized version of the instrument, presented in Appendix B, reflects these revisions.

3.6.7 Population and Sampling Strategy

The population for this study is defined as actual visitors to cultural heritage sites. Specifically, since the Adaptive Augmented Reality (AAR) model is designed for the Kota Mahsuri heritage site, the evaluation's target population consists of individuals whose experience and expectations are directly relevant to the application's intended operational context.

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The sampling method employed was convenience sampling, focused on maximizing the ecological validity of the evaluation. Participants were selected through an on-site convenience approach, whereby individuals already present at the Kota Mahsuri heritage site were invited to participate in the study. This technique was intentionally chosen not for mere ease of recruitment, but to satisfy the critical requirement of testing the AAR model within its intended, real-world context. Conducting the evaluation on-site allowed participants to interact with the Mahsuri AR application during their actual visit, capturing authentic and immediate reactions which reflect the genuine user experience.

3.6.8 Actual Data Collection

The data collection process for evaluating the usability of the Mahsuri AAR application was conducted at Kota Mahsuri, Langkawi, over three days, from October 8 to October 10, 2021. The primary objective of the study was to evaluate the usability of The Mahsuri application among visitors at Kota Mahsuri, a culturally significant heritage site. To ensure the assessment was both comprehensive and reliable, a validated questionnaire was employed as the primary evaluation tool. This ensured that the collected data were consistent and met rigorous standards of reliability and validity.

The candidates were selected through a convenience sampling method, whereby individuals already present at the site were invited to participate in the study. This approach allowed for ease of recruitment while capturing a diverse range of user experiences. Participants were asked to engage with the Mahsuri AR application during their visit, exploring its features and functionalities in a real-world setting. After using the application, they were encouraged to complete the questionnaire to provide detailed feedback on usability.

Conducting the evaluation on-site offered several advantages. It allowed participants to interact with the application in its intended context, capturing authentic and immediate reactions. This real-time feedback provided valuable insights into the application's performance in a heritage environment, where factors such as cultural significance, environmental conditions, and visitor expectations play a crucial role in shaping user experiences. By leveraging this approach, the study aimed to ensure that the usability assessment accurately reflected the practical applicability and

effectiveness of the Mahsuri AR application in enhancing the visitor experience at Kota Mahsuri. The diverse demographic of visitors ensured a comprehensive dataset for analyzing the usability of the Adaptive Augmented Reality (AAR) model in enhancing the visitor experience at heritage sites.

3.7 Phase 5: Conclusion

The final phase of the study focuses on drawing conclusions, where the evaluation results are analyzed, and the findings are discussed in relation to the expected outcomes. The evaluation of the AAR application is analyzed using descriptive analysis. Key findings from the study, including the conceptual model of AAR, the developed prototype, and the evaluation results, are reported and contribute to the existing body of knowledge. The research design is illustrated in Figure 3.1.

3.8 Summary

This chapter discusses the methodology adopted in this study. The methodology from Vaishnavi and Kuechler (2008) and vom Brocke et al. (2020) was adapted to consist of five main stages to accomplish the goal of the study: (i) awareness of the problem, (ii) suggestion, (iii) development, (iv) evaluation, and (v) conclusion. Each activity and the expected outcome are clearly formulated for this study.

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CHAPTER FOUR

CONCEPTUAL MODEL OF AAR

4.1 Overview

This chapter discusses the proposed conceptual model of Adaptive Augmented Reality (AAR), which is the main contribution of the study. Based on several previous works on adaptive augmented reality, the core knowledge elements of the adaptive concept were identified. Components of such a concept were gathered and offered as a formal definition using model analysis, which covered four models.

4.2 AAR Core Components

The four models are A2R Museum Augmentation Model by Damala and Stojanovic (2012), Conceptual framework for Adaptive Multimodal Interfaces in Mobile Augmented Reality by Abidin et al. (2017), Conceptual framework for Adaptive Augmented Reality by Tenemaza et al. (2015) and finally, i-ARA Adaptive Augmented Reality by Hervás et al. (2013). They were fully discussed in the previous chapter in section 3.5.3, which shows that user profiles, media, interaction, environment data, and device components are all included as elements in each of the AR models.

All the previously stated models include the User Personalization and Environment elements as adaptive augmented reality components. To identify the characteristics of the users or their interests, user information (such as age, gender, and height) and physiological conditions are acquired. The augmented content is typically based on the characteristics chosen and related to the multimedia contents (images, videos,

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animations, text, audio comments, sounds, and 3D objects). Depending on the device used to interact with the content, interaction can take the form of gesture, word, touch, or sight. To enable this, the majority of models make use of the device's sensors. In the case of a mobile phone, sensor data (camera, GPS, compass, and so on) was utilised to adapt relevant information about an intriguing object, location, or even a person. It is obvious that the core components of adaptive apps are the environment (EV) and user personalization (UP). As a result of analyzing these four models, the core components of Adaptive Augmented Reality were proposed as:

$$\boldsymbol{A^2R} = \{\boldsymbol{EV}, \boldsymbol{UP}, \boldsymbol{OC}\}$$

$$\boldsymbol{where}$$

$$\boldsymbol{EV} = \{\boldsymbol{medium}, \boldsymbol{media}, \boldsymbol{interaction}, \boldsymbol{context}\}$$

$$\boldsymbol{UP} = \{\boldsymbol{bio\ data\ such\ as\ age}, \boldsymbol{gender}, \boldsymbol{height}, \boldsymbol{etc.}\}$$

$$\boldsymbol{OC} = \{\boldsymbol{service}, \boldsymbol{networked}, \boldsymbol{devices}\}$$

& $\boldsymbol{whenever\ sensors\ are\ available}$, *the UP adaptive component makes us*

& *context in EV refers to how creative the storytelling is applied*

Figure 4.1. Core components of AAR

As presented in Figure 4.1, AAR consist of three main elements, which are Environment (EV), User Personalization (UP) and Other Components (OC). EV refers to changes in the visual, audio, and interactive elements of the content being displayed. The user model is the focus of UP, which involves sensing users' data to react to EV and pre-planned scenarios. Adaptivity of the EV can be applied accordingly toward users' data, such as age, gender, and height. Other components (OC) are defined by

the service or device layers, including camera, GPS, accelerometer and other components provided in the device.

As depicted in Figure 4.1, the EV component for AAR is closely linked to the elements of DST in the Interaction cluster, Appeal cluster and Construction cluster. The EV components are dealing with the visual, audio, and interactivity elements of the content being displayed; while the three elements in the cluster of appeal are to give an impact on the experience of viewers toward the digital story, and the elements in the cluster of construction are related to the content creation of the digital story. Furthermore, elements in interactive meant the audience can interact and provide input to shape the story. On the other hand, the User Experience design model proposed by Hammady et al. (2018) can be adapted for designing the prototype or the actual application.

4.3 Digital Storytelling Core Elements

The digital storytelling conceptual model comprises core elements as a guideline for producing digital storytelling (DST), which can be interactive or non-interactive (Tenh, 2013). As depicted in Figure 4.2, the core elements are divided into four distinct clusters (origin, interaction, construction, and appeal), and each element plays a significant part in storytelling. Considering storytelling in AR can also be interactive or non-interactive, the conceptual model is considered in this study.

First cluster, Origin that focuses on elements that establish the story. Two elements in the cluster are intention and the element ‘user contribution’, which also belongs to the Interaction cluster. The element intention means a digital story begins with a purpose by the digital storyteller, which will be disclosed at the finale. At the same time, the

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element user contribution allows the audience to participate in the DST content development process.

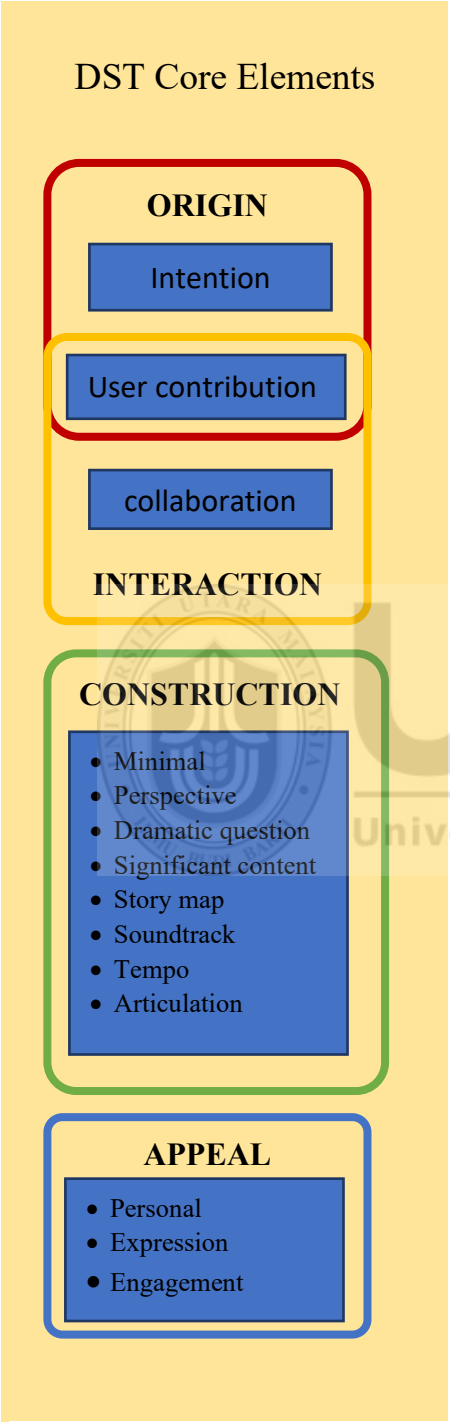


Figure 4.2. Core elements of DST

The other element in the Interaction cluster is collaboration. Both elements in this cluster imply that the audience interacts with the digital storytelling by giving input that helps shape the story. Comparably, collaboration is more about interacting with other users to create an experienced digital storytelling.

There are eight elements in the Construction cluster, which are minimal, perspective, dramatic question, significant content, story map, soundtrack, tempo, and articulation. Basically, the elements in this cluster are related to the content creation of the digital story.

Essentially, minimal in DST recommends that a story not be too long by composing the crucial content of the story and dismissing the irrelevant. Perspective is about the attempt of DST to convey a certain message from a certain standpoint, whether in a first-person or third-person viewpoint. A dramatic question is an element that establishes a question

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that creates suspense in the digital storytelling to keep the audience's attention from the beginning until the story finishes. Significant content in DST refers to the story as the primary focus, with multimedia being used to highlight the story's essence and substance. Story map indicates that a DST should have the classic arc of storytelling, which is beginning, middle, and closure and the elements of tension, conflict, and resolution. The soundtrack element suggests a sensible and cautious use of music as a supportive element in digital storytelling since music has the ability to evoke the audience's emotions. The element tempo talks about the rhythm and beat of the story, which might impact the audience's interest and retention of the digital story. Lastly, articulation is concerned with the use of the digital storyteller's own voice in telling the story, which would have a greater influence on the DST.

Appeal was designed to impact the experience of viewers toward the digital story; there are three elements, which are personal, expression and engagement. The element personal in DST suggested that the story should be a personal tale of the storyteller for people to feel affection for his life. Next, expression is mostly concerned with transmitting messages or information in particular DST situations without the use of narration. Alternatively, symbolism and metaphor can be employed to be interpreted by the audience. Then, engagement is the element of engaging and the capacity of a story to captivate an audience through emotion or content, to the point that the story feels real to them.

The DST component is a core structural element chosen to define and drive the AAR model. DST is selected because it offers a narrative structure recognized in the literature for its capacity to transform passive content consumption into an emotionally

resonant and engaging experience, which sustains user interest far better than traditional informational displays. This narrative vehicle acts as the primary mechanism for delivering personalized content; the DST Core Elements (such as interaction, appeal, and construction) are tightly integrated with the AAR system's Environment Components to dynamically tailor the viewing experience in real-time. Crucially, the integration of DST directly addresses the identified research gap concerning the lack of a unified model. Thus, DST's contribution is the essential link that enables personalized content to be delivered in a compelling and memorable way, justifying the model and the need for the current study.

4.4 AAR Conceptual Model

The Adaptive Augmented Reality (AAR) Conceptual Model (in Figure 4.3) presents an innovative framework that integrates Digital Storytelling (DST) and adaptive AR core components to enhance user engagement in AR applications. This holistic approach bridges technical robustness with user-centric design, offering a transformative pathway to create interactive and engaging AR applications.

Figure 4.4 reveals a significant interdependence between the EV component for AAR and the elements within the Interaction, Appeal, and Construction clusters of DST. The EV components are intricately linked to the visual, audio, and interactivity aspects of the displayed content. Meanwhile, the elements within the Appeal cluster aim to influence viewers' experiences of digital stories, and those within the Construction cluster are associated with the creation of digital story content. Importantly, the interactive elements signify that the audience can actively engage and contribute to shaping the narrative. AAR is an evolution of earlier AR technologies and presents a

promising frontier for developing robust augmented reality applications. This adaptation allows the display of relevant digital content based on user characteristics and real-time context.

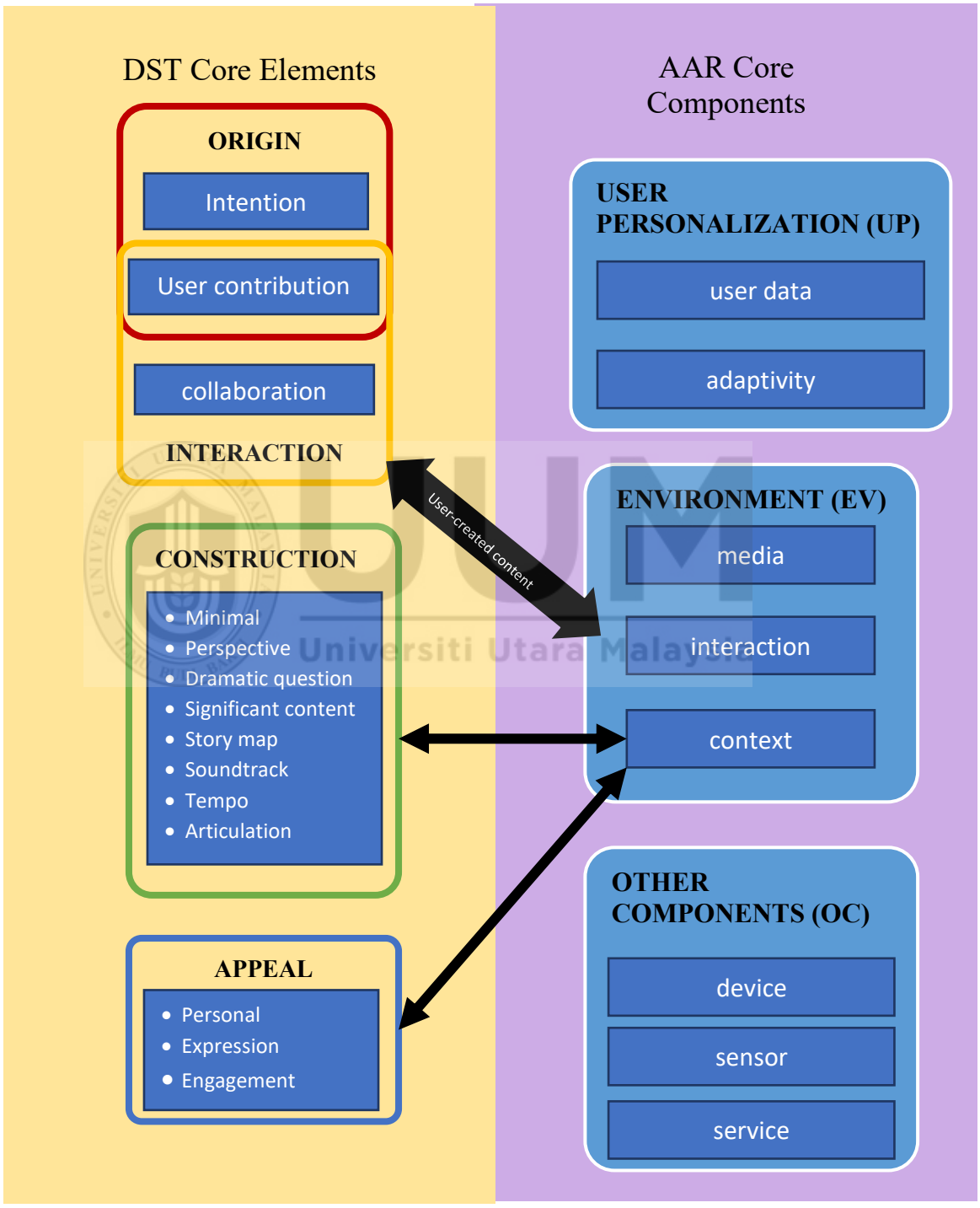


Figure 4.3. Conceptual Model of AAR

The proposed AAR model is geared toward augmenting user experience and engagement. To build this cohesive model, existing frameworks in Augmented Reality and Digital Storytelling are critically scrutinized. The objective is to synthesize these components into a singular model that effectively elevates engagement and enhances overall user experience. The resulting model was then submitted to experts for review and subsequently amended based on their recommendations, ensuring a refined and well-informed approach to AAR development.

4.5 Expert review process and findings

The proposed AAR Conceptual Model was presented to experts for review, and modifications were made based on their recommendations to ensure a more refined and well-informed approach to AAR development. The expert review process played an important role in refining the proposed AAR Conceptual Model. After completing the initial version of the model, it was presented to three experts. Each expert evaluated the model, focusing on the clarity of the components, the logical coherence of the adaptive mechanisms, and the feasibility of implementing the model in real AAR applications. The involvement of three experts is methodologically justified, as literature suggests that a minimum of three experts is sufficient to establish reliability while reducing individual bias and ensuring a diversity of perspectives (Lynn, 1986; Rubio et al., 2003). Furthermore, the approach aligns with findings from Dumas et al. (1995) who found that involving three to five experts is an effective range for obtaining informed judgments and generating meaningful recommendations.

Detailed feedback was collected through structured comments through the expert review form (appendix A). These insights guided a series of revisions that strengthened

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the conceptual foundation, resolved ambiguities, and improved alignment with current technological and theoretical developments. Through this evaluative process, the model evolved into a more coherent, practical, and contextually grounded framework for Adaptive Augmented Reality design. The review of the Adaptive Augmented Reality (AAR) conceptual model was conducted by three experts with varied professional backgrounds as presented in Table 4.1.

Table 4.1 Expert's Profile

Experts	Fields	Experiences (years)
Expert A	Human-Computer Interaction (HCI) and Interaction Design.	8
Expert B	Computer Science and Creative Technology.	17
Expert C	Immersive Digital Media: Game Development, AR, VR, and Metaverse	8

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The expert review of the Adaptive Augmented Reality (AAR) conceptual model adapting Storytelling in Heritage produced a combination of supportive and critical perspectives concerning its clarity, logical flow, and practical application. The evaluation involved three experts, each with extensive backgrounds in Human Computer Interaction and Multimedia. Their assessments collectively affirmed the model's relevance and practicality while identifying several areas requiring refinement, particularly in terms of structure, clarity, and integration among components.

The experts provided mixed feedback on the conceptual model's clarity, logical flow, and practicality:

1. Clarity and Understanding: Experts B and C agreed that the conceptual model is generally clear and logical. They found that it combines storytelling and augmented reality in a way that fits user experience design. However, Expert A pointed out that the model lacks a clear starting point and that the bidirectional arrows make the flow confusing. Expert A also noted that the functions of some elements, such as User Personalization and Environment, are not clearly explained. This shows that the model needs clearer labels and explanations to make it easier to understand.

2. Flow and Connections: All three experts felt that the logical flow and connections among the components need improvement. Expert B pointed out that while the relationship between AAR Core Components and Digital Storytelling (DST) Core Elements is shown, it is not clearly explained. The expert recommended illustrating how adaptive features, such as user data and environmental interaction, influence storytelling outcomes.

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3. Practicality: All experts agreed that the model is practical and suitable for use in heritage environments. Expert C highlighted that the integration of User Experience Design, Storytelling Elements, and Adaptive Components forms a solid foundation for developing immersive applications. Expert B supported this view, adding that the model's modular structure allows it to be applied to different cultural and contextual scenarios.

4. Overall Design: Expert C acknowledged that the overall structure of the model aligns well with digital storytelling and multimedia design theories. However, Experts A and B identified key weaknesses affecting clarity and understanding.

The experts agreed that this distinction must be clarified to make the model more consistent and easier to interpret.

The expert review demonstrated that while the conceptual model of Adaptive Augmented Reality (AAR) adapting Storytelling in Heritage is grounded in strong theoretical logic and is practical for heritage applications, its clarity and internal consistency require refinement. The experts agreed that the model provides a solid foundation for connecting storytelling theory, user experience design, and augmented reality technology; however, they also identified several areas that need improvement to enhance the model's interpretability and effectiveness.

Expert A found the model somewhat unclear due to the use of ambiguous bidirectional arrows and the absence of a defined starting point, which makes it difficult to interpret the flow of relationships among variables. The expert also noted that several key components, particularly User Personalization and Environment, lack sufficient explanation of their functions and interconnections. To address this, Expert A recommended refining the visual layout of the model, clarifying directional relationships, and providing concise labels and descriptions for each component. The expert further suggested that the role of the User Experience Design Process should be clearly defined, whether it functions as a methodological guide or an integral part of the conceptual framework.

Expert B focused on the lack of explicit articulation between the AAR Core Components and the Digital Storytelling (DST) Core Elements. The expert highlighted the need to show how adaptive elements such as user data, context, and environmental input influence storytelling construction and user engagement. Additionally, Expert B

emphasized that the model should incorporate iterative feedback mechanisms to represent the continuous and adaptive nature of user experience design. The expert also recommended specifying the functions of components like devices, sensors, and services, as well as illustrating how the Environment component can adapt to different cultural or historical contexts within heritage settings.

Expert C agreed that the model is theoretically sound and practically applicable for heritage contexts. The expert acknowledged that it demonstrates logical coherence and integrates relevant concepts from user experience and digital storytelling effectively. However, Expert C also recognised the need for greater visual clarity, more detailed definitions, and clearer flow among constructs to make the model easier to interpret and apply in real-world scenarios.

Collectively, the experts concluded that the model possesses strong theoretical grounding and significant practical potential, but it requires refinement to strengthen its explanatory precision. The recommended improvements include clarifying relationships among constructs, defining the role of each component, illustrating iterative and adaptive processes, and enhancing the visual organisation of the diagram. Implementing these refinements will improve the model's conceptual clarity, usability, and robustness, ultimately increasing its value as a framework for developing adaptive storytelling experiences in heritage-based augmented reality applications.

4.6 Refinement of Model Based on Expert Review.

The issues identified from expert review were addressed, and improvements were made to the AAR conceptual model. Several corrections and enhancements were implemented. First, the overall structure and clarity of the model were refined.

Bidirectional arrows that seemed to be confusing were replaced with unidirectional arrows wherever applicable, distinctly highlighting the direction of relationships to improve comprehension.

To ensure a comprehensive understanding, the “Other Components” section was elaborated. Broad categories such as “device,” “sensor,” and “service” were given examples for clarity. Similarly, the “Environment” components examples and notation were given to make it more understandable. The role of the User Experience (UX) Design process was refined and retained as an integral part of the model to represent the development process of AAR applications. This ensures a user-centered approach throughout, guiding the design from understanding user needs to testing and refining the application.

With these refinements, the AAR conceptual model achieves improved clarity. The final model, showcasing the enhanced structure and integration of these elements, is presented in Figure 4.4. The final version of the AAR Conceptual Model has been refined based on expert feedback to ensure it is both clear and easy to understand. The updated model combines the DST Core Elements and AAR Core Components to guide the development of immersive and adaptive augmented reality applications. The DST Core Elements focus on creating meaningful, engaging stories that resonate with users, while the AAR Core Components ensure the technical foundation is robust, adaptive, and capable of delivering personalized experiences. Finally, these elements combined seamlessly to create AR applications that are immersive, engaging, and tailored to user needs, making them particularly well-suited for cultural heritage projects

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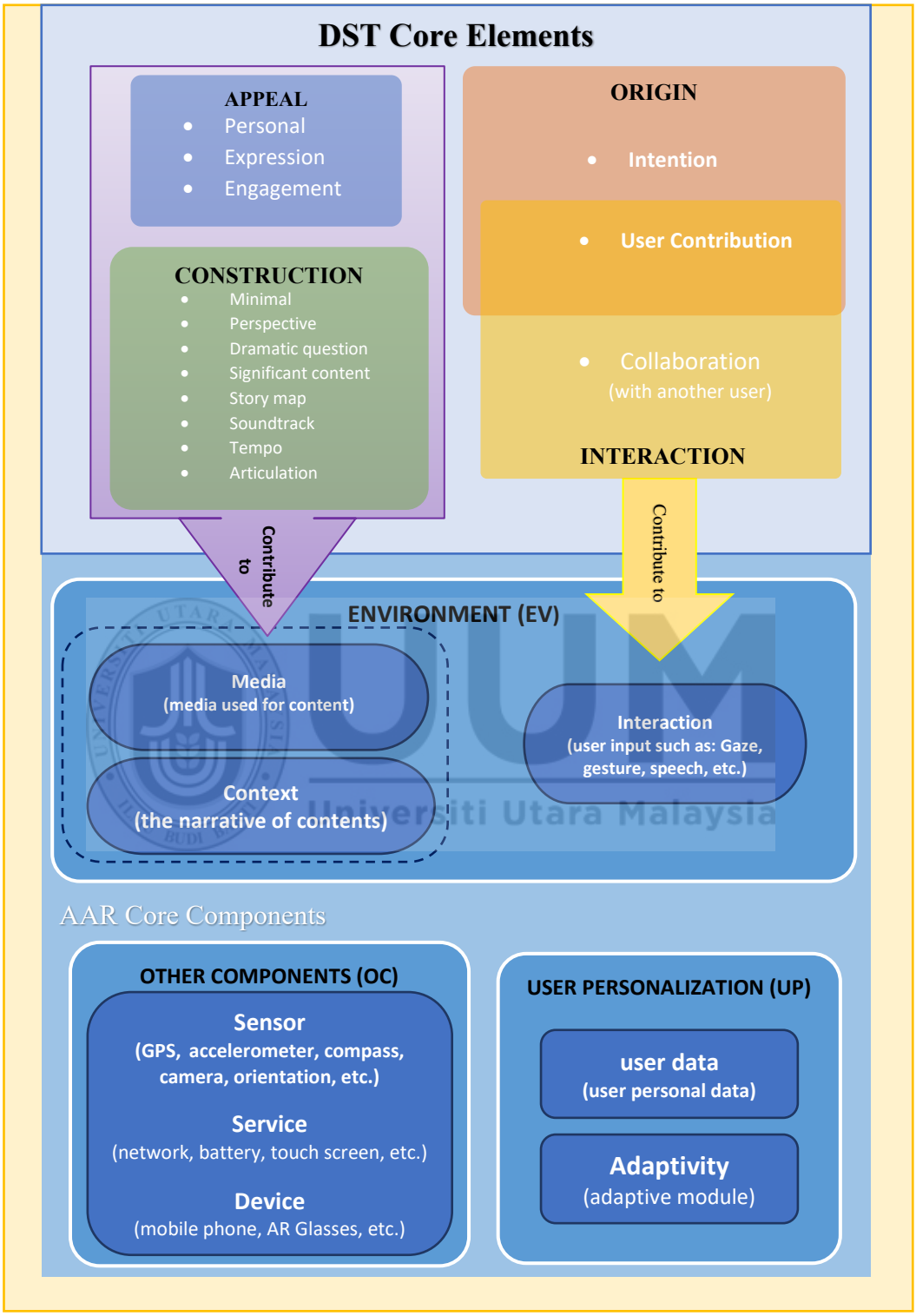


Figure 4.4. Final Model of AAR

4.7 Summary

This chapter presented the conceptual model for Adaptive Augmented Reality (AAR), developed through an analysis of existing frameworks in adaptive AR and digital storytelling (DST). The core components of AAR: Environment (EV), User Personalization (UP), and Other Components (OC) are identified and linked to DST elements such as interaction, appeal, and construction clusters. The chapter emphasizes the integration of user characteristics and real-time environmental data to create adaptive and engaging AR experiences. By adapting UX design principles and leveraging insights from prior models, this chapter lays the foundation for a holistic approach to heritage storytelling, with the proposed model undergoing expert review for refinement and validation.

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CHAPTER FIVE

AAR PROTOTYPE DEVELOPMENT AND USABILITY EVALUATION

5.1 Overview

This chapter discusses the development of the adaptive augmented reality prototype and its usability evaluation. The AAR prototype application was developed for the heritage site of Kota Mahsuri in Langkawi, Malaysia and the usability evaluation was also conducted at the site. The evaluation seeks to collect user feedback on the usability of the AAR application in the context of heritage site visiting. Prior research has emphasized the importance of prioritizing user experience and usability when introducing novel technological approaches in heritage sites. Accordingly, this chapter provides a comprehensive account of the selection of evaluation methods, the recruitment of participants, and the data analysis approach adopted for the usability evaluation.

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5.2 Development of The Mahsuri AAR Prototype Application

In this stage, an AAR prototype was developed based on the final AAR Conceptual Model. The development process followed the UX Design framework while seamlessly integrating the DST Core Elements to create an Adaptive Augmented Reality (AAR) application. Below are the 5 steps undertaken, which follow the UX Design Process suggested by Hammady, Ma and Powell (2018). The steps are: Understand, Define, Ideation, Design and Test. The key processes at each stage are discussed as follows:

5.2.1 Step 1: Understand

In the first step, the foundation of the AAR prototype was laid by identifying the application's purpose and expected function. The core function was defined as the ability to personalize narrative activities based on user data, particularly dividing users into two categories: adults and children. For adults, the application provided educational content and information about the exhibits at Kota Mahsuri, while children engaged with game-based content and AR storytelling for a more playful and interactive experience. Immersive aspects, including QR code scanning for audio narratives, 3D object interactions, AR games, and AR storytelling, were identified as key features to create an engaging user experience. The key features of the application are shown in Table 5.1. These considerations ensured that the application would meet the diverse needs of its audience.

Table 5.1 Key features of the AAR

Features	**Description**
Personalized Content Delivery	Receive tailored educational information. Enjoy content designed to be entertaining and age-appropriate
AR Storytelling	Immerse in captivating, story-driven experiences with visual and auditory effects. Explore 3D objects through interactive, playful manipulation.
Audio and visual	Access to immersive and captivating experiences with visual and auditory effects.

5.2.2 Step 2: Define

The second step involved building a clear framework for the application's structure and functionality. The mobile phone was selected as the platform due to its ubiquity

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and cost-effectiveness. The application was designed to be installed on users' phones, making it easily accessible. A scenario was created where museum visitors could scan artifacts to view relevant digital content overlaid in AR. Additionally, activities tailored to user categories (adults and children) were incorporated, providing a personalized experience. The UI elements, such as the menu, buttons, and background, adopted a traditional theme to align with the cultural context of Kota Mahsuri. Interaction methods were also defined, including the use of the phone camera for artifact scanning and height measurement to categorize users. Other interactions, such as gestures and touch inputs, were included to enhance usability.

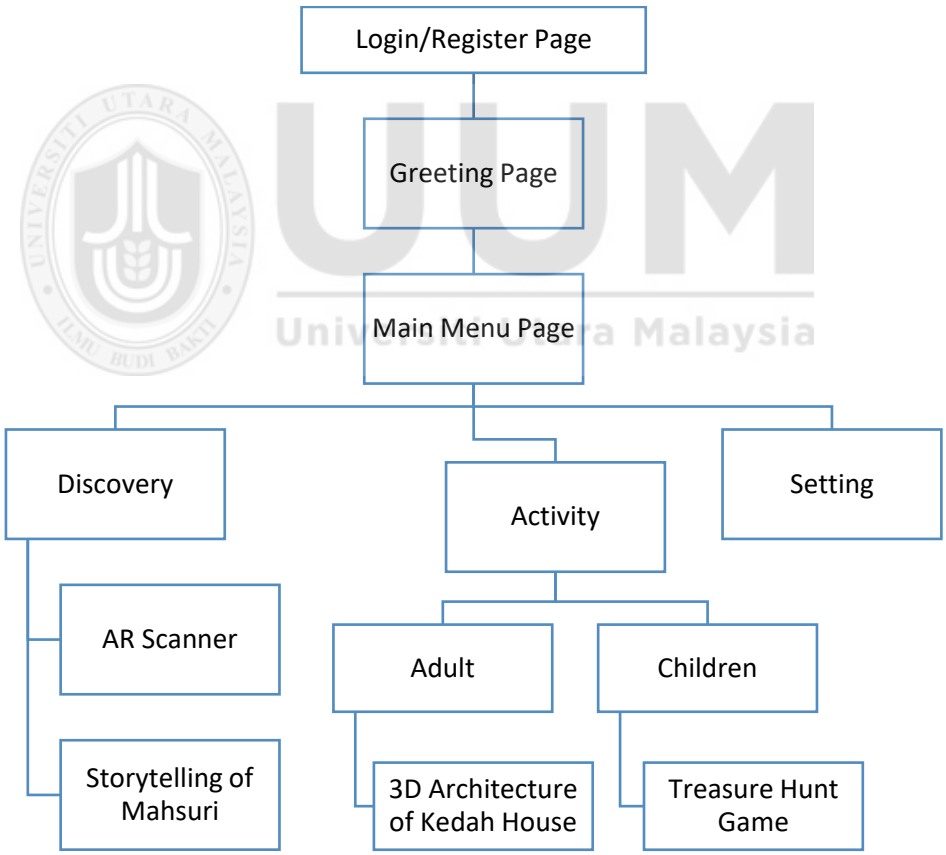


Figure 5.1 Architecture Flow of the application.

Figure 5.1 outlines the navigation and functionality of The Mahsuri application. It begins with the Login/Register Page, where users can log in or create an account as

the credentials for the user. After successful login, users are greeted on the Greeting Page and then directed to the Main Menu Page, the central hub for all features. The greeting page also plays a role in engaging the user after logging into the application by making the user feel welcomed and that the app is personalized. In the Main Menu Page, users can choose to explore the exhibition in Kota Mahsuri with the assistance of the AR Scanner and enjoy the legendary story of Mahsuri. Furthermore, users can interact with the personalized activity based on the age category.

In the first option, which is the Discovery section, users can explore augmented reality features specific to Kota Mahsuri. Through the AR Scanner, users can scan markers in the exhibition to trigger audio narrations of artifacts, available in both Malay and English. Additionally, the Storytelling of Mahsuri feature offers an immersive narrative of the legendary Mahsuri tale, enhanced with a 3D augmented object that users can manipulate (rotate, resize, and move). Navigation buttons allow users to control the story's flow, and the narration is also available in dual languages (Malay and English).

Next, the Activity section provides personalized content tailored to user categories, whether they are adults or children. Adults are augmented with the 3D augmentation of Kedah house architecture, while children may engage in a Treasure Hunt Game, which encourages them to discover artifacts exhibited in Kota Mahsuri. Finally, the Settings page allows users to adjust the music volume, return to the main menu, or exit the application. This structured and user-friendly flow ensures an engaging and intuitive experience for all users, seamlessly combining cultural storytelling with modern technology.

5.2.3 Step 3: Ideation

In this step, the focus was on exploring creative ideas to craft a user experience that is both engaging and meaningful. A well-thought-out design concept was developed to shape the UI, incorporating traditional themes and cultural elements that resonate with the museum's heritage. The goal was to create an application that is visually captivating and functionally intuitive, appealing to users of all ages. This stage prioritized innovation and creativity, ensuring the application not only stands out but also delivers an enriching experience that is both educational and entertaining. The key design ideas are summarized in Table 5.2.

Table 5.2 Design elements

Design elements	**Description**
Color Palette 	Three main colors, white, gold and black, are reminiscent of traditional luxury and heritage aesthetics, making it culturally relevant.
Typography 	The text uses a modern sans-serif font that balances readability with a contemporary look, complementing the traditional background.
Pattern 	Traditional motifs are used in the background to reflect traditional design, aligning with the cultural and heritage theme of a museum.

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The design elements of the application are thoughtfully crafted to create an engaging, culturally meaningful, and user-friendly experience. A carefully chosen color palette of white, gold, and black reflects traditional luxury and heritage, fostering a sense of connection to the museum's cultural essence while maintaining a modern and elegant look. The use of a modern sans-serif font ensures readability and accessibility for users of all ages, striking a balance between contemporary usability and aesthetic sophistication. Subtle traditional motifs in the background enhance the visual depth and authenticity of the design, tying the interface to its cultural and historical context without overwhelming the user. These elements work together harmoniously to humanize the application, making it visually appealing, functionally reliable, and emotionally resonant, ensuring it stands out as both an educational tool and an engaging digital experience.

5.2.4 Step 4: Design

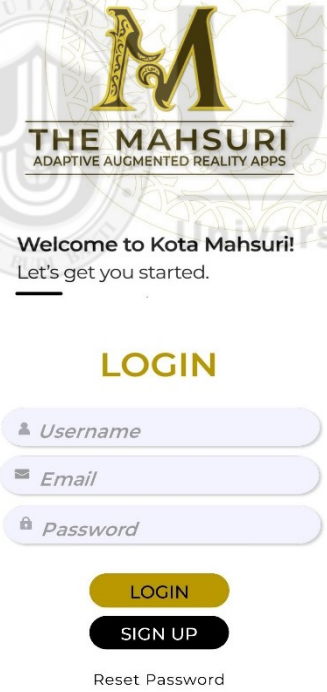
The design phase focused on visualizing and creating the prototype. A detailed storyboard was developed to outline the application's UI, media, and user interactions. This storyboard provided a visual representation of how users would navigate through the app, interact with artifacts, and engage with AR activities. Additionally, the AAR core components, such as sensors, user personalization, and adaptive media, were refined and rectified through the storyboard process. The design phase translated the ideas from the ideation stage into a tangible and cohesive prototype that aligned with the project's goals.

The storyboarding method was used for visualizing the design and concept of The Mahsuri AAR prototype. It showed how the important elements of the AAR model

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would be integrated into the prototype development. Table 5.2 shows the storyboard illustrating important features and concepts through scenes based on the components and elements imposed in the AAR conceptual model. The storyboard provides a guiding framework for keeping the development process on track with the aims of the AAR conceptual model.

Table 5.3 Storyboard of The Mahsuri AAR application.

Scene	App Pages	Description
Login		The login page is the first page for a new user to register their credential to proceed to use this application. Existing user may login by entering the details to proceed. Element related: The login page incorporates: - User Personalization (UP) by collecting user credentials. This allows the system to personalize the experience by adapting content based on user-specific data, such as preferences and usage history. This step ensures that the user is immediately integrated into an adaptive experience, setting the stage for personalization throughout the application.

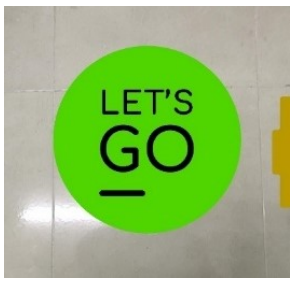
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Scene	App Pages	Description
Greeting		The greeting page is to acknowledge the user and begin the exploration using the application. Elements related: This scene aligns with: - Appeal Cluster of the Digital Storytelling (DST) model, particularly the "personal" element. By acknowledging the user directly, the application establishes an emotional connection and sets a tone of engagement, helping the user feel valued and involved from the start.
Main Menu		The main menu page allows the user to choose the type of content they want to proceed with. Discover: allows users to explore the exhibition in Kota Mahsuri with the audio narration, including the narrative of the legend of Mahsuri. Activity: provide the customised activity according to the age category of the user, either adult or children. Element related: The main menu scene reflects on - Environment (EV). It allows users to choose between discovering content they desire to follow.

Scene	App Pages	Description
		- The dual-choice menu also demonstrates the Interaction Cluster of the DST model by empowering users to shape their journey within the app.
AR scanner		Through the AR Scanner, users can scan markers in the exhibition to trigger augmented audio narrations of artifacts, available in both Malay and English. Element related: This scene incorporated: - Environment (EV) component emphasizes interaction, context, and multimedia. - Other Components (OC): Uses device sensors (e.g., AR camera, accelerometer) to enable marker recognition and adapt the AR content. - This interaction aligns with the Interaction Cluster of the DST model, as it allows users to actively engage with the exhibits.

Scene	App Pages	Description
Mahsuri story		The Storytelling of Mahsuri feature offers an immersive narrative of the legendary Mahsuri tale, enhanced with a 3D augmented object that users can manipulate (rotate, resize, and move). Navigation buttons allow users to control the story's flow, and the narration is also available in dual languages (Malay and English). Element Related: This scene incorporated: - Environment (EV) component focuses on enhancing user engagement through dynamic and adaptive media. User interactions with 3D models (e.g., resizing, rotating) provide hands-on engagement, creating an interactive and educational experience. - The DST core elements of construction, appeal, and interaction clusters are reflected here. For example: Construction: Significant content (Mahsuri story) and tempo (narrative control).

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Scene	App Pages	Description
		Appeal: Personal (story relevance), engagement (interactive 3D objects). Interaction: interaction to navigate through the story and be able to choose the desired language.
Activity	 	The activity section provides personalized content tailored to user categories, whether they are adults or Kids. In the activity scene, an AR camera is used to determine whether the user is an adult or a child based on the height of the phone from the marker. If the adult (green) leads to Kedah House, while the kid (turquoise) starts the treasure hunt game. Elements related: This scene incorporated: - User Personalization (UP). By using the AR camera to determine user categories based on device height. This use of real-time user data showcases the adaptability of the AAR model.

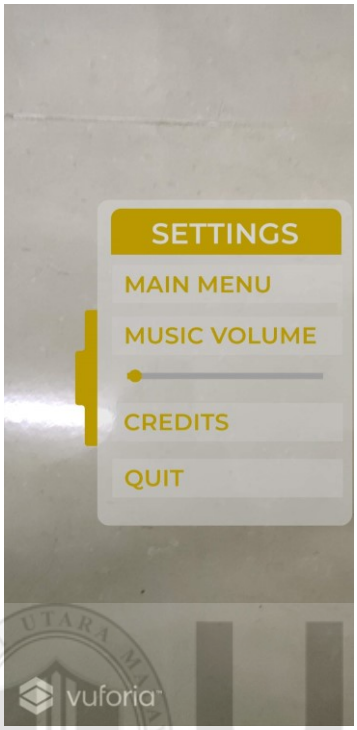
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Scene	App Pages	Description
Kedah House		From the previous scene, adults are augmented with the 3D augmentation of Kedah house architecture and their functions. Here, the user is also able to manipulate the 3D model. The narration is also provided in dual language (English and Malay). Elements Related: This scene incorporated: - Environment (EV): 3D model augmentations and dual-language narration for an interactive experience. - Construction Cluster of the DST model emphasizes significant content (the architectural and cultural heritage of Kedah). The dual-language narration further enhances accessibility and immersion. - Additionally, the activities align with the Interaction Cluster, as they actively engage users in culturally immersive tasks.

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Scene	App Pages	Description
Game: treasure hunt		Children may engage in a Treasure Hunt Game, which encourages them to discover artifacts exhibited in Kota Mahsuri. Clues are given to lead them to find the 6 artifacts on the cube. Instructions will be given at the beginning to help children complete the game. Element related: This scene is related to clusters in the DST model: - Interaction Cluster elements. By engaging users in discovering artifacts, the game promotes user contribution to the narrative, as children actively shape their experience. - Appeal Cluster is aligned with the gamified design, creating a captivating and engaging experience. Clues and instructions ensure the activity is accessible and enjoyable.

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Scene	App Pages	Description
Setting		The settings page allows users to adjust the music volume, return to the main menu, or exit the application. Elements related: This scene reflects: - User Experience Design (UXD) principles. By allowing users to adjust settings, such as music volume or navigation, this scene enhances usability and ensures a seamless user experience. These features demonstrate the AAR model's commitment to creating a user-centric application that adapts to individual preferences and needs.

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Integrating elements of the AAR model into each scene of the Mahsuri AAR application prototype creates a cohesive user experience that adapts to user needs. The prototype showcases how Environment (EV), User Personalization (UP), and Other Components (OC) interact with Digital Storytelling (DST) and User Experience Design (UXD) to achieve an immersive and culturally relevant augmented reality experience with custom activities, interactive storytelling and gamification elements. All these elements work together to tailor content to the user, celebrate cultural heritage, and create an immersive, interactive experience exploring the cultural heritage site of Kota Mahsuri.

The AAR conceptual model serves as the backbone of The Mahsuri AAR prototype, incorporating the main components: User Personalization (UP), Environment (EV), Other Components (OC), and Digital Storytelling (DST) to provide a substantive improvement in the system's functionality and user experience. The unique contributions of each element work together to provide an immersive, personal, culturally meaningful experience for the user.

User Personalization (UP) is essential for content personalization for individual users. The prototype could gather user data (such as age, height, and preferences) through elements like the login page and adaptive sensors (such as GPS and camera) in activity sections to deliver content accordingly. For example, in this application, children are redirected into a treasure hunt game; adults are directed towards the 3D model of Kedah House. In addition, this personalization also helps in keeping the application relevant and engaging for users of various age groups, thus increasing the overall educational and cultural value of the experience.

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Environment (EV): Using interactive and multimedia components promotes more involvement from users. A featured AR scanner allows guests to recognize markers on physical displays and produce narrations. The narrative of the Legend of Mahsuri and the architecture of Kedah House is displayed using 3D objects, drawing viewers into the tale and capturing their attention. Furthermore, dual-language narration makes for a densely populated storytelling target group. The EV components in the AAR conceptual model focus on dynamic media and interactivity that enable users to actively and meaningfully reconstruct aspects of their experiences with cultural artefacts.

OC (Other Components) use the advancement of devices and sensors to enhance user experience. The prototype leverages device cameras, accelerometers, and AR markers to provide adaptive capabilities. For example: different groups of users through camera sensors and 3D object manipulation (rotate, zoom and move).

Digital Storytelling (DST) is the key component of the prototype, expanding the narrative of Mahsuri's legend through 3D object interaction. By incorporating construction elements like significant content, dramatic questions, and narrative flow, the application delivers an emotionally resonant and structured story. The appeal and interaction clusters engage users through interactive 3D objects and gamified activities like the treasure hunt. These elements allow users to shape their experiences, fostering a deeper connection to the content.

The storyboard for the Mahsuri AAR application prototype was designed based on the AAR conceptual model, integrating core components such as Environment (EV), User Personalization (UP), and Other Components (OC) with Digital Storytelling (DST). This approach is to ensure an immersive and culturally relevant AR experience with interactive storytelling, gamification, and custom activities. Using this storyboard as a guide, a functional prototype was then developed to bring the concept to life.

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5.2.5 Prototype Development

The Prototype development phase involves developing the Mahsuri AAR application using Unity software, incorporating all key features and elements of the AAR conceptual model. The activities focus on creating a complete system prototype that integrates all modules, such as navigation, AR features, and personalized storytelling,

while ensuring compatibility and seamless functionality. The prototype includes key features like login and user personalization, navigation via a main menu, marker-based AR scanning, and immersive activities. The purpose of this prototype is to test and refine the application for usability. By evaluating its features and user experience in a real-world context, developers can identify and address any issues, ensuring the app is intuitive, engaging, and aligned with its cultural and educational goals. This testing phase will refine the prototype into a seamless, adaptive AR application that offers users a personalized and immersive exploration of Mahsuri's legend while preserving its cultural significance.

5.2.6 Step 5: Test

In this step, the developer and researcher collaborated to refine the application into its final prototype, ready for usability testing in a real-world setting. Rigorous testing was conducted to identify and fix technical issues, such as AR interaction bugs and media inconsistencies, ensuring a seamless user experience. User feedback was collected to address gaps and refine the application, focusing on improving functionality, accessibility, and engagement. The developer resolved technical challenges, while the researcher ensured alignment with project goals and user needs. This iterative process resulted in a polished, functional prototype prepared for real-world evaluation and usability testing.

5.3 Usability Evaluation of The Mahsuri AAR Application

This chapter describes the evaluation of the usability of the AAR application. The study was done at Kota Mahsuri, Langkawi, from 8 October 2021 to 10 October 2021. The targeted participants are the visitors of Kota Mahsuri. The approach of evaluation

was done by randomly asking visitors of Kota Mahsuri to use the AAR application and fill in the questionnaire afterwards. End-user perspectives are important input for measuring the usability of the application. The following sections present the findings of this study. The target population of this study are the visitors of the Kota Mahsuri, Langkawi. In this study, the visitors who went to Kota Mahsuri were randomly asked to take part in the survey within three days. Collectively, there were 219 visitors taking part in the evaluation after trying to use the Mahsuri AAR application.







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5.3.1 Demographics

The assessment process involved 202 participants, and their demographic background is presented in Table 5.4. The gender distribution was nearly equal, with 102 males

(50.5%) and 100 females (49.5%). Most participants were above 30 years old (48%), while 34% of young adults ranged from 19 to 30 years old and 18% were aged 8 to 18 years old. Regarding experience with augmented reality (AR) applications, 186 participants (84.9%) had never used them before, while 33 participants (15.1%) had prior AR experience. In terms of daily mobile device usage, 75 participants (37.1%) always used a mobile device, 60 (29.7%) often used it, 48 (23.8%) used it sometimes, 10 (5.0%) rarely used it, and 9 (4.5%) never used a mobile device. Table 5.4 provides a detailed overview of the participants' demographics.

Table 5.4 Demographic of respondents

No	Items	Features	Frequency	Percentage (%)
1	Gender	Male	102	50.5%
		Female	100	49.5%
2	Ages	8 - 18	36	17.8%
		19 - 30	69	34.2%
		Above 30	97	48.0%
3	Have you used Augmented Reality (AR) applications before this?	Yes	31	15.3%
		No	171	84.7%
4	How often do you use mobile devices in a day?			

	Never	Rarely	Sometime	Often	Always
f	9	10	48	60	75

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5.3.2 Descriptive Analysis

The usability evaluation questionnaire yielded results across various dimensions of the application's usability. The questionnaire items, measuring the constructs of Comprehensibility, Manipulability, Engagement, Engrossment, and Total Immersion,

were based on a 5-point Likert scale. This ordinal rating scale quantified user attitudes, with participants selecting the response that best reflected their perception. The scale anchors were: 1 (Strongly Disagree), 2 (Disagree), 3 (Neutral), 4 (Agree), and 5 (Strongly Agree). Consistent with the data preparation procedures in section 3.6.4, the reverse-scored items (COMPRE2, MANI1, MANI2, MANI3, and ENGG5) were recoded to ensure a unidirectional scale where higher scores indicate a more positive response. Therefore, a higher mean score for an item or construct indicates a more positive assessment of the application's usability.

Table 5.5 Mean and Standard Deviation for Comprehensibility

COMPREHENSIBILITY			
NO	**Question**	**Mean**	**Standard Deviation**
COMPRE1	I thought the amount of information displayed on the screen was appropriate	4.28	.894
COMPRE2	I thought that the information displayed on screen was confusing	4.19*	.717
COMPRE3	I thought the words and symbols on screen were easy to read.	4.30	.988
COMPRE4	I thought that the information displayed on screen was consistent	4.15	.983
OVERALL		**4.23**	**.639**

Table 5.5 presents the comprehensibility data, with an overall mean score of 4.23 (SD = 0.639), indicating users largely perceived the application as clear and easy to understand. The highest mean score (M = 4.30, SD = 0.988) was recorded for item COMPRE3 "I thought the words and symbols on screen were easy to read.", suggesting strong performance in the clarity of visual and textual elements. Similarly,

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users agreed that “I thought the amount of information displayed on screen was appropriate” COMPRE1, M = 4.28, SD = 0.894). The item with the lowest mean score was COMPRE4: “I thought that the information displayed on screen was consistent” (M = 4.15, SD = 0.983). COMPRE2, the negatively worded item “I thought that the information displayed on screen was confusing”, was reverse-coded. It means 4.19 (SD = 0.717), therefore, signifies a strong rejection of the idea that the application was confusing. Collectively, these results confirm that the application successfully delivered information in a clear and readable format.

Table 5.6 Mean and Standard Deviation for Manipulability

MANIPULABILITY			
NO	**Question**	**Mean**	**Standard Deviation**
MANI1	I found the device difficult to hold while operating the AR application	4.18*	0.752
MANI2	I felt that my arm or hand became tired after using the AR application	4.37*	0.716
MANI3	I felt that I was losing grip and dropping the device at some point	4.28*	0.743
OVERALL		**4.27**	**0.578**

As depicted in Table 5.6, the mean and standard deviation for the application’s manipulability focus on the physical effort and comfort of device use. With an overall mean of 4.27 (SD = 0.578), the data indicate a strong positive perception of ease of handling. Since all three items were negatively worded and subsequently reverse-coded, the high mean scores reflect a significant disagreement with the difficulties presented in the questions. Specifically, users most strongly disagreed with the

statement “I felt that my arm or hand became tired after using the AR application” MANI2 (M = 4.37, SD = 0.716). Similarly high scores were observed for MANI3 (M = 4.28, SD = 0.743) and MANI1 (M = 4.18, SD = 0.752), indicating that users did not feel they were losing grip or that the device was difficult to hold. These findings collectively suggest that the AR application did not impose significant physical strain or difficulty in handling the device during operation.

Table 5.7 Mean and Standard Deviation for Engagement

ENGAGEMENT			
NO	**Question**	**Mean**	**Standard Deviation**
ENGG1	I liked the activity because it was novel	4.28	1.067
ENGG2	I liked the type of activity	4.33	0.994
ENGG3	I wanted to spend time participating in the activity	4.19	1.062
ENGG4	It was easy for me to use the AR application	4.30	0.921
ENGG5	I found the AR application confusing	4.47*	0.663
OVERALL		**4.31**	**0.693**

Table 5.7 summarizes the mean scores and standard deviations for user engagement with the application. The overall mean score of 4.31 (SD = 0.693) indicates a very high level of positive engagement among participants. This positive finding is consistently reflected across the individual items. The highest level of agreement was recorded for the item ENGG5, “I found the AR application confusing,” which has been reverse-coded (M = 4.47, SD = 0.663). This means signifies the strongest disagreement with the confusing nature of the application, reinforcing its ease of use and clarity. Additionally, users highly rated the activity itself, with the highest mean among the positive statements given to ENGG2, “I liked the type of activity.” (M = 4.33, SD = 0.994). High scores were also observed for the application’s perceived ease of use,

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ENGG4 (M = 4.30, SD = 0.921) and its novelty, ENGG1 (M = 4.28, SD = 1.067). Even the lowest-rated item, ENGG3, "I wanted to spend time to participate in the activity," (M = 4.19, SD = 1.062), still demonstrates strong positive agreement. These results collectively confirm that the AR activity successfully captured user interest and was perceived as enjoyable and easy to use.

Table 5.8 Mean and Standard Deviation for Engrossment

ENGROSSMENT			
NO	**Question**	**Mean**	**Standard Deviation**
ENGRSS1	I was curious about how the story would progress	4.16	0.986
ENGRSS2	I was often excited since I felt like part of the story	4.14	1.009
ENGRSS3	If interrupted, I looked forward to returning to the story	3.79	1.268
ENGRSS4	I was more focused on the story rather than any external distraction	3.77	1.250
OVERALL		**3.96**	**0.776**

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Table 5.8 presents the mean scores and standard deviations for engrossment, which measures the user's level of immersion and attention to the application's narrative. The overall mean score is 3.96 (SD = 0.776), indicating moderate-to-high agreement that the application captured user attention, though it is slightly lower than the scores reported for Comprehensibility and Manipulability. The highest scores reflect a strong connection to the AR story: "I was curious about how the story would progress" ENGRSS1, (M = 4.16, SD = 0.986) and "I was often excited since I felt as if I was part of the story" ENGRSS2, (M = 4.14, SD = 1.009). This suggests the narrative structure and participatory elements were effective in driving initial interest and emotional connection.

In contrast, the lowest means were observed for items related to sustained attention and persistence. Users showed the least agreement with being focused on the story rather than external distractions, ENGRSS4 (M = 3.77, SD = 1.250) and looking forward to returning to the story if interrupted, ENGRSS3 (M = 3.79, SD = 1.268). The wider standard deviations on these two items also suggest greater variability in user experiences regarding distraction and sustained immersion. While the AR application successfully established curiosity, the data suggests that maintaining deep, distraction-proof immersion may present a slight limitation. Some improvement to the narrative flow or interactivity to strengthen these aspects of the user experience.

Table 5.9 Mean and Standard Deviation for Total Immersion

TOTAL IMMERSION			
NO	**Question**	**Mean**	**Standard Deviation**
IMMER1	The story felt so authentic that it made me think that the virtual characters/objects existed for real	3.92	1.105
IMMER2	I felt that what I was experiencing was something real, instead of a fictional story	3.91	1.103
IMMER3	I was so involved in the story that, in some cases, I wanted to interact with the virtual characters/objects directly	3.80	1.227
IMMER4	I was so involved that I felt that my actions could affect the story	3.90	1.235
OVERALL		**3.88**	**0.895**

Table 5.9 presents the mean scores and standard deviations for Total Immersion, reflecting the user's perception of realism and presence within the AR experience. The

overall mean score is 3.88 (SD = 0.895). The highest-rated item, “The story felt so authentic that it made me think that the virtual characters/objects existed for real” IMMER1, (M = 3.92, SD = 1.105), and “I felt that what I was experiencing was something real, instead of a fictional story” IMMER2, (M = 3.91, SD = 1.103), suggest the application achieved a successful degree of perceptual realism. These results indicate that the fidelity of the AR environment was sufficient to generate a sense of authenticity. The slightly lower mean was recorded for IMMER3 (“I was so involved in the story, that in some cases I wanted to interact with the virtual characters/objects directly,” (M = 3.80, SD = 1.227). While still positive, this result, alongside the wide standard deviation, suggests variability in the extent to which users felt an urgent desire for agency or direct interaction, which is a key component of deep presence. The finding that users felt their actions could affect the story IMMER4 (M = 3.90, SD = 1.235) supports the effectiveness of the narrative structure but does not fully translate into an overpowering impulse to interact, aligning with the pattern of slight limitations observed in sustained Engrossment.

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The analysis across all five constructs reveals that the application successfully established strong usability and initial engagement, but it struggled to create deep and lasting immersion. As depicted in Figure 5.2, the high mean scores for Comprehensibility (M = 4.23) and Manipulability (M = 4.27), coupled with high initial Engagement (M = 4.31), confirm the AR application is highly successful in meeting fundamental usability requirements; users found the interface clear, the device handling easy, and the activity novel. However, scores for the experiential constructs of Engrossment (M = 3.96) and Total Immersion (M = 3.88), while still positive, were measurably lower. This pattern suggests that while the system is technically sound and

easily operated, it struggles to translate initial interest into a state of deep, distraction-proof presence. This outcome may be a result of the AR format itself, where the real-world environment remains visible and is a constant source of external distraction, or it may point to design limitations in the narrative structure (ENGRSS4, M = 3.77) and the ability to foster a compelling sense of user agency (IMMER3, M = 3.80). Therefore, the primary critique is that the application excels functionally but fails to consistently induce the cognitive and emotional detachment from reality necessary for truly profound immersion.

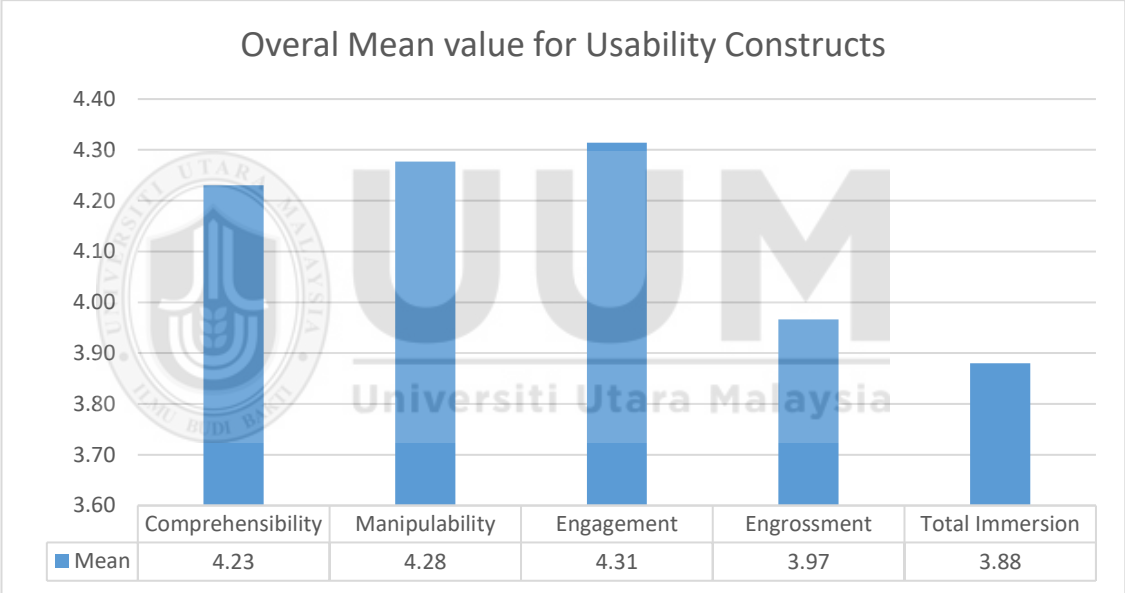


Figure 5.2 Overall Mean Value for Usability Constructs.

In conclusion, the evaluation confirms the application's strong foundation, particularly in usability and initial engagement (Comprehensibility and Manipulability). However, the findings also leave room for improvement in translating functional ease into deep and sustained immersion. In addressing these, refining the narrative elements to foster greater agency and reduce external distraction is required. These focused

improvements will elevate the user experience, ensuring the application is not only functional and accessible but also successful in achieving its full potential.

5.4 Summary

This chapter presents the findings from the prototype development and usability evaluation questionnaire conducted to assess the application's effectiveness and user experience. The evaluation focused on key dimensions, including comprehensibility, manipulability, engagement, engrossment, and total immersion. The results highlight that the application was well-received, with strong scores in comprehensibility, manipulability and engagement. Participants appreciated the application's novelty and suitability for advanced technological exploration of heritage sites as key strengths. Conversely, data related to the depth of immersion suggest areas for targeted refinement. These findings collectively confirm that the application meets its primary objective as an interactive heritage exploration tool, providing both validation of its potential and specific insights for future design iterations.

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CHAPTER SIX

CONCLUSION

6.1 Overview

This chapter presents an in-depth discussion of the findings from the previous chapters, tying them back to the objectives and framework established at the outset of the research. It begins by revisiting the objectives outlined in Chapter One, assessing how each objective has been addressed and achieved through the study. This discussion also highlights the contributions made by the study to the existing body of scientific knowledge, emphasizing its significance in advancing research in Adaptive Augmented Reality (AAR) for heritage sites. Furthermore, this chapter addresses the limitations encountered during the research process and identifies potential areas for future work to enhance and build upon the findings. This chapter concludes with a concise synthesis of the study's findings, highlighting the theoretical, practical and functional contribution of the study and suggesting avenues for future research.

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6.2 Objectives Achievement

The primary goal of this study was to develop a conceptual model for Adaptive Augmented Reality (AAR) applications tailored to heritage sites. This was accomplished through a systematic approach that addressed three specific research objectives:

RO1: To analyse the core components of Adaptive Augmented Reality (AAR) for cultural heritage sites.

This objective identifies and examines the fundamental components necessary to develop AAR applications in heritage settings. The analysis aims to provide a formal definition of AAR, ensuring a clear understanding of their roles and relevance in enhancing AAR application within cultural heritage contexts. The results, presented in Section 4.2 of Chapter 4, demonstrate the achievement of this objective by providing AAR core components. This also addresses RQ1: What are the core components of the adaptive augmented reality (AAR) conceptual model for a cultural heritage site?

RO2: To propose an AAR conceptual model for a cultural heritage site.

Building on the findings from RO1, this objective aimed to develop a comprehensive conceptual model that integrates the identified components into a cohesive framework tailored to heritage contexts. The model serves as a strategic guide for designing and implementing AAR applications that enhance the heritage experience. Section 4.7 in Chapter 4 outlines the conceptual model and its practical implications, successfully addressing RQ2: How do the components identified fit into the AAR model for a cultural heritage site?

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RO3: To evaluate the usability of the AAR prototype, created as a proof of concept based on the proposed AAR model.

This objective focused on evaluating the usability of the proposed Adaptive Augmented Reality (AAR) model through its deployment in a practical application and the subsequent collection of user feedback. The findings confirmed the model's effectiveness in delivering an engaging and user-friendly experience for visitors to heritage sites. The discussion in Section 5.3 addresses this objective and provides a

comprehensive response to RQ3: How usable is the AAR prototype for cultural heritage sites developed based on the proposed AAR conceptual model?

The accomplishment of these objectives underscores the study's success in meeting its research goals. The integration of local context, user needs, and environmental factors in the development of the AAR model, along with its practical validation, contributes valuable insights to the application of adaptive augmented reality in heritage settings. These findings provide a foundation for future research and development in designing user-centric AAR applications that enhance cultural heritage experiences.

6.3 Research Contributions

This study makes several significant contributions to the field of AAR, particularly in the context of heritage sites. The primary contribution is the development of conceptual models for AAR, which integrate elements of Digital Storytelling (DST) and User Experience (UX) to enhance the visitor experience at heritage sites. These models provide a structured approach to designing AAR applications, emphasizing adaptability and user-centric design. Another notable contribution is the evaluation of these conceptual models through practical implementation using an AAR application. This assessment not only validates the models but also provides insights into their applicability and effectiveness in real-world settings. The findings from this study add to the growing body of knowledge on AAR and its potential to transform heritage site experiences by making them more immersive and interactive. The contributions of this study are categorized into theoretical, practical and functional contributions. These contributions are further discussed below:

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6.3.1 Theoretical Contributions

The conceptual model of Adaptive Augmented Reality (AAR) for cultural heritage sites is a major contribution, yielding significant theoretical advancements across multiple disciplines, including information technology (IT), multimedia design, and software development.

Specifically, within the Information Technology (IT) domain, this study first addresses a critical gap in the existing literature by synthesizing the core components of Augmented Reality (AR), digital storytelling (DST), and user experience (UX) into a single, unified framework. This interdisciplinary integration enriches the theoretical foundations of adaptive AR, establishing a structured blueprint for future scholarly inquiry within cultural heritage and various applied contexts.

Furthermore, the model makes a direct contribution to multimedia design through its Storytelling Adaptation element, pioneering the development of richer, more engaging experiential narratives. This offers a novel methodology for effectively conveying cultural heritage, making history and traditions highly accessible and interactive for global audiences. In the field of Human-Computer Interaction (HCI), the model structurally prioritizes user experience, furnishing crucial insights for creating multimedia content that is not only robust but also meaningful and highly usable, thus establishing a higher benchmark for user-centric principles in cultural education technology.

Beyond theory, the study provides a practical and methodological contribution to software development. It delivers a validated framework that directly guides developers by defining the essential components and interaction logic necessary to

build adaptive AR applications that are both structurally sound and contextually relevant. Finally, the systematic process used to verify and refine the conceptual model, particularly through expert validation and rigorous usability testing, provides a valuable and replicable evaluation methodology for future software development and IT research.

This study's contribution lies not only in its theoretical advancements but also in its practical implications for designing adaptive, user-centric AR applications, making it a valuable resource for academia and industry alike.

6.3.2 Practical Contribution

The study's contribution extends directly to practical significance and societal impact by providing an actionable framework for industry and cultural institutions.

The conceptual model serves as a validated Development Guideline for AR Applications, simplifying the design and implementation process for developers creating Storytelling Adaptation experiences at heritage sites. This practical contribution not only streamlines implementation but also ensures applications are functionally aligned with cultural preservation goals.

The model also directly addresses usability and user engagement; the User-Validated Concept provides empirical evidence that the framework is not only theoretically sound but also highly effective and accessible in a real-world setting, significantly enhancing its credibility. By prioritizing user experience, the model ensures the resulting AR applications achieve Improved User Engagement, making them intuitive and accessible educational tools that foster a deeper connection with historical sites.

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On a broader scale, the model's structure contributes to preserving cultural heritage by leveraging AR technology to present history in an interactive and appealing format, which helps combat the growing disconnect between younger generations and historical traditions. This focus on engagement facilitates raising public awareness, which can boost heritage tourism and attract the funding necessary for the maintenance and sustainability of cultural assets.

In summary, the proposed conceptual model is not only a practical guide for AR application development but also a catalyst for raising awareness and appreciation of cultural heritage. Its usability validation ensures real-world applicability, while its broader implications contribute to cultural, educational, and economic domains.

6.3.3 Functional Contribution

The AAR prototype developed based on the proposed conceptual model offers a significant functional contribution with wide-ranging implications in the domains of cultural heritage, education, and interactive technology.

The AAR prototype is the study's crucial deliverable, serving as a robust proof-of-concept that transforms the theoretical framework into a tangible, working tool. This demonstration establishes the practical feasibility of Adaptive Storytelling Adaptation within a complex cultural heritage environment. Functionally, the core innovation lies in the capacity for highly Personalized User Experiences: the application adapts content based on the user's age (differentiating between adults and children), which ensures the delivered historical narrative is consistently age-appropriate, maximally educational, and exceptionally engaging across diverse demographics.

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This functional capability translates directly into profound Cultural and Educational Impact. The integration of the Mahsuri narrative ensures that cultural stories are not merely told, but experienced, thus creating a deeper emotional and intellectual connection with the audience. By incorporating Langkawi's specific cultural, architectural, and historical elements, the interactive prototype ensures the active preservation and dissemination of local traditions and knowledge. Furthermore, the strategic use of storytelling, games, and digital object illustrations transforms passive learning into an enjoyable and immersive educational experience, positioning the application as a valuable tool for museums and educational institutions.

The prototype's approach to content delivery represents a novel innovation in AR. The specific combination of adaptive content, interactive games, and explanatory digital illustrations sets a high benchmark for how AR can effectively convey complex cultural and historical information. Ultimately, the successful functional embodiment of the conceptual model demonstrates its efficacy, providing a foundation for future research and development in adaptive AR systems across tourism and entertainment.

The AAR prototype serves as the study's crucial functional embodiment, directly validating the conceptual model's feasibility and effectiveness in a real-world cultural heritage setting. The prototype's core strength lies in its technological innovation to deliver highly personalized, adaptive storytelling based on user characteristics. This functional success translates into profound cultural and educational impact by actively preserving local traditions, boosting audience engagement, and establishing a high benchmark for the development of adaptive AR systems in tourism and education.

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6.4 Research Limitations and Future Work

While this study successfully achieved its objectives, it also highlighted several limitations that provide opportunities for future research and development. These limitations reveal areas where the current work could be refined and expanded to enhance its applicability, robustness, and impact in the field of Adaptive Augmented Reality (AAR) for cultural heritage.

6.4.1 Generic Nature of the Conceptual Model

The conceptual model proposed in this study was intentionally designed as a generic framework to broadly represent the principles and potential applications of AAR systems. This approach ensures flexibility and adaptability across various contexts, allowing the model to be applied to a wide range of heritage sites and user demographics. However, the broad nature of the framework may dilute its effectiveness in addressing the unique characteristics of specific sites or user needs. For instance, a model tailored to historical landmarks with complex architectural features might require specialized adaptations, such as advanced spatial mapping or targeted storytelling elements that reflect the site's unique cultural significance. Similarly, user groups, such as families with children or international tourists, may have distinct preferences and engagement styles that a generic model may not fully accommodate. Future research could explore developing customized versions of the model, incorporating site-specific features, user-centric design principles, and localized storytelling narratives to maximize the relevance and effectiveness of AAR systems.

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6.4.2 Testing Constraints

The empirical testing of the model was conducted at Kota Mahsuri, Langkawi, during the COVID-19 pandemic, which posed significant challenges. The restrictions on gatherings, travel limitations, and health protocols resulted in a reduced number of participants. This smaller and less diverse sample size limits the generalizability of the findings, as the feedback collected may not fully represent the varied perspectives of potential users. Additionally, conducting the study in a single heritage site may not provide a comprehensive understanding of how the model performs in different contexts. Heritage sites differ widely in terms of their historical significance, geographical features, visitor demographics, and technological infrastructure. Future research should aim to overcome these limitations by conducting tests at multiple heritage sites, each with unique characteristics. Larger and more demographically diverse sample sizes would also enhance the reliability of the results, providing a broader dataset to validate the model's effectiveness and adaptability. Furthermore, longitudinal studies involving repeated interactions with the AAR system could offer deeper insights into user behavior, engagement patterns, and the system's long-term impact on cultural appreciation.

6.4.3 Limited Activities and Storytelling Components

The Mahsuri AAR application developed for this study included a limited selection of interactive activities and storytelling content. While these components were sufficient for initial testing, they may not have fully demonstrated the model's potential for creating immersive and engaging experiences. Storytelling is a powerful tool in cultural heritage interpretation, capable of evoking emotional connections and deepening visitors' understanding of historical narratives. Expanding the range and

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complexity of storytelling elements could significantly enhance the application's appeal. For example, incorporating multimedia narratives, such as audio-visual recreations, interactive timelines, and first-person accounts of historical events, could create a richer and more engaging user experience. Interactive activities, such as augmented reality treasure hunts, gamified learning modules, or role-playing scenarios, could further boost user participation and retention. These enhancements would also allow researchers to evaluate the model's ability to handle more complex interactions and diverse content types, providing valuable insights for future development.

6.4.4 Opportunities for Future Development

Building on these limitations, future research could focus on several key areas. First, the conceptual model could be refined to incorporate adaptive features tailored to specific heritage contexts and user groups. This refinement would involve deeper collaboration with heritage experts, cultural historians, and user experience designers to ensure that the model aligns with the unique needs and characteristics of each application. Second, expanded testing across diverse heritage sites and user demographics would provide a more comprehensive understanding of the model's strengths and weaknesses. Third, the development of richer and more varied storytelling content and activities would showcase the full potential of AAR systems, demonstrating their capacity to create immersive and meaningful heritage experiences.

By addressing these limitations, future studies can significantly enhance the impact and applicability of Adaptive Augmented Reality in cultural heritage. This work has the potential to advance the preservation and promotion of cultural heritage, making it

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more accessible, engaging, and relevant to diverse audiences in a rapidly evolving technological landscape.

6.5 Summary

This chapter summarizes the study's findings and confirms that the core research goal to develop and validate an Adaptive Augmented Reality (AAR) Model for heritage sites was successfully achieved. The study followed a clear process: identifying necessary AAR components, integrating them into a cohesive model and an operational framework, and confirming their effectiveness through a validated prototype.

The research delivers several specific contributions. The primary theoretical contribution is the AAR Model itself. This model advances the literature by combining the distinct principles of augmented reality, digital storytelling, and measured user experience into a single, structured theory. It directly addresses a critical gap in AAR literature by explaining the relationship between adaptive components and user engagement. This model provides a clear, evidence-based methodological guide for developers.

From a practical standpoint, the study offers a well-defined, validated model that directly guides developers. The model simplifies the design process, ensuring applications are user-centred, contextually relevant, and aligned with cultural preservation goals. This contribution extends to the creation of engaging educational tools that incorporate immersive storytelling, fostering a deeper connection between users and cultural heritage. The functional contribution, embodied by the prototype,

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further showcases the practical implementation of these theoretical concepts through adaptive storytelling and personalized content, demonstrating how technology can actively preserve and promote cultural narratives.

While the study achieves its objectives, it acknowledges certain limitations that open clear avenues for future research. The generic nature of the conceptual model, while ensuring broad applicability, would benefit from further tailoring to specific types of heritage sites or user demographics. Additionally, testing constraints, primarily due to the COVID-19 pandemic, limited the number of participants and testing environments; future studies should expand sample sizes and conduct assessments across diverse settings.

The study's findings underscore the transformative potential of AAR in preserving and promoting cultural heritage. By enabling adaptability and interactivity, the proposed model enriches the way users interact with heritage sites, offering an immersive narrative experience. This innovation has far-reaching implications for cultural preservation, tourism, and education, making it a valuable contribution to both academia and industry. The successful development and validation of the AAR conceptual model lay a solid foundation for continued exploration and innovation in this field, reaffirming the critical role of adaptive technologies in bridging the gap between tradition and modernity.

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Appendix A

Expert Review Form

SCHOOL OF MULTIMEDIA TECHNOLOGY AND COMMUNICATION
COLLEGE OF ARTS & SCIENCES

EXPERT VALIDATION FORM VALIDATION OF CONCEPTUAL MODEL FOR ADAPTIVE AUGMENTED REALITY ADAPTING STORYTELING IN HERITAGE

I am Tenh Hock Kuan (902998), a PhD candidate from the Awang Had Salleh Graduate School at the College of Arts & Sciences, Universiti Utara Malaysia. I am working under the guidance of Assoc. Prof. Dr. Syamsul Bahrin Zaibon. The focus of the study is on developing a conceptual model known as Adaptive Augmented Reality Model adapting Storytelling in Heritage. Given your extensive academic and research background in Human-Computer Interaction, particularly in augmented reality or Mobile Applications domains, I am kindly seeking your valuable opinions, suggestions, and recommendations. Your expertise would greatly contribute to the refinement and enhancement of the conceptual model for adaptive augmented reality in heritage, especially in context of Malaysia.

Best Regards,
Tenh Hock Kuan

CONSENSUS FORM

1. I have been actively doing research or extensively teaching in the area of Human-Computer Interaction or Augmented Reality or Mobile Application domain for more than five (5) years.

2. I understand that the expert review process is designed to gather information and comments in improving the proposed model.

3. I understand that no part of the proposed model may be reproduced, stored in the retrieved system, or transmitted in any form or by any means, electronic, mechanical photocopying, recording, or otherwise, without prior permission from the researcher and her supervisors.

4. I understand that the researcher will not identify me by name in any report using information obtained from the questionnaire and that my confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions.

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5. I have read and understood the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.

6. I am given a copy of this consent form.

……. ……..

Name : Date and Official Stamp

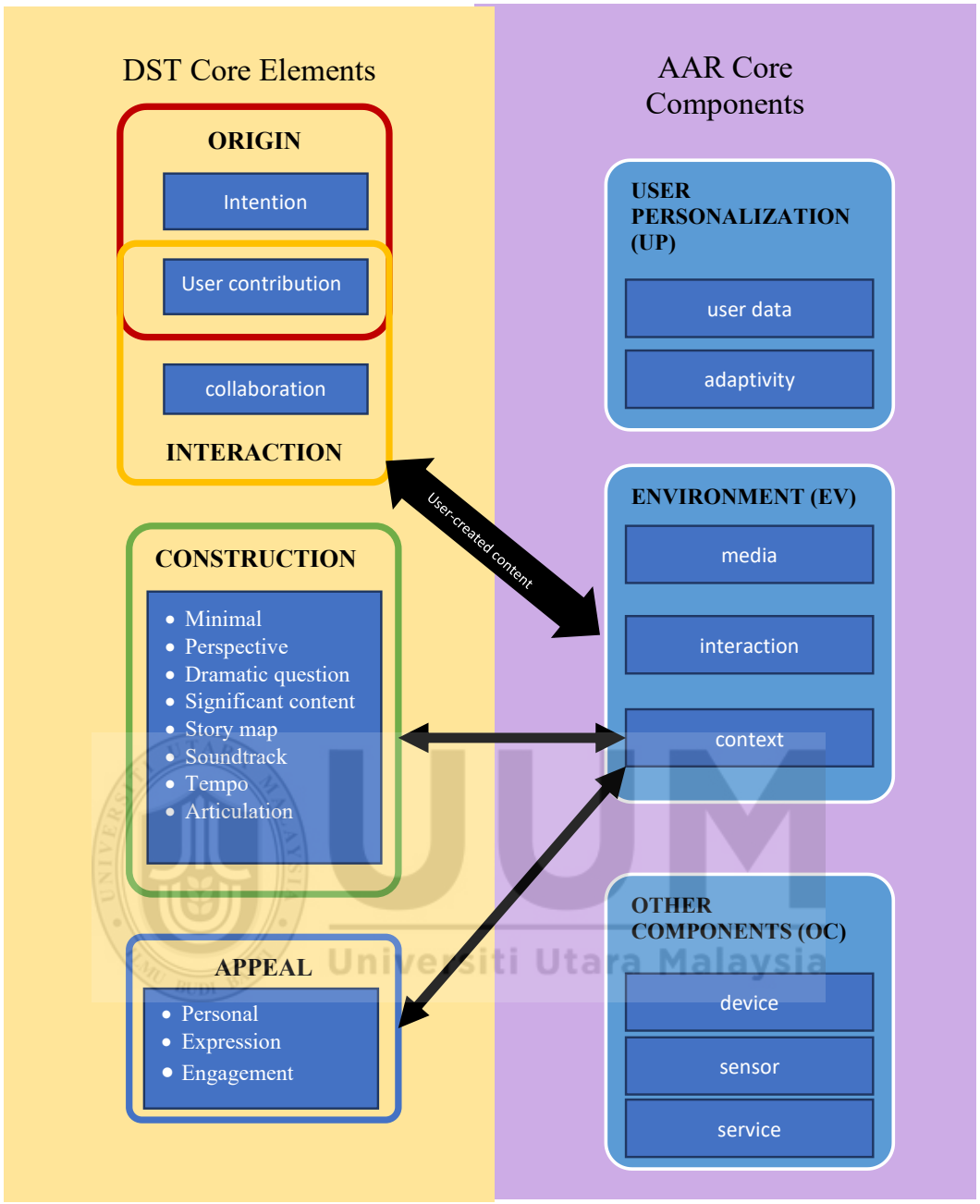


Figure 1 Conceptual Model of AAR adapting Storytelling in Heritage.

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EXPERT DEMOGRAPHIC DETAILS

1. Area of Expertise:
2. Years of Experience:

EXPERT REVIEW QUESTIONS

1. Based on the conceptual model of AAR adapting Storytelling in Heritage, please tick (/) your choice.

Question	YES	NO
A. The proposed conceptual model of AAR is rational and understandable.		
B. The connection and flows for the conceptual model of AAR of all the attributes are rational.		
C. The proposed conceptual model is practical for designing and implementing an AAR in heritage environments.		
D. Finally, the whole design and conceptual model is understandable.		

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2. Please write your further comments below, if any.

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THANK YOU!!

Appendix B

Questionnaire for AAR Usability Evaluation

Penilaian Realiti Terimbuh Adaptif dalam Warisan

Evaluation of Adaptive Augmented Reality in Heritage

Responden yang dihormati, dengan mengisi borang soal selidik ini, anda turut sertai dalam proses penilaian kebolehpenggunaan aplikasi Realiti Terimbuh Adaptif (AAR) di Kota Mahsuri.

Maklumat yang diberikan akan dirahsiakan dan digunakan hanya untuk rujukan yang akan dilaporkan tanpa nama untuk tujuan penerbitan akademik. Terima kasih kerana meluangkan masa mengisi borang soal selidik ini.

Dear respondent, by filling up this questionnaire you are taking part in evaluating the usability of the Adaptive Augmented Reality (AAR) application at Kota Mahsuri.

The information supplied will be treated as confidential and will be used for research purposes which may be reported anonymously in academic publications. Thank you for your time filling this questionnaire.

Arahan *Instruction*
Terdapat TIGA (3) bahagian dalam soal selidik ini. Bahagian A adalah perincian Demografi, bahagian B adalah kemahiran diri, dan bahagian C adalah Penilaian. Sila jawab semua butiran di ruang yang disediakan untuk bahagian A dan B. Bahagian C mengandungi 31 item berdasarkan skala Likert 5 mata, mulai dari 1 - "sangat tidak setuju", hingga 5 - "sangat setuju". Sila nyatakan jawapan anda berdasarkan skala. *There are THREE (3) section in this questionnaire.* *Section A is the Demographic detail, section B is personal skill, and section C is the Evaluation.* *Please answer all the detail in the space provide for section A and B.* *Section C contains 34 items based on a 5-point Likert scale,* *ranging from 1 –"strongly disagree", to 5 – "strongly agree".* *Please indicate your response based on the scale.*

A	Butiran demografi *Demographic detail*		
	Nama / *Name*		
	Umur / *Age*		
	Jantina / *Gender*	Lelaki / Male	Perempuan / Female

B	Kemahiran Diri *Personal Skill*				
1	Adakah anda pernah menggunakan aplikasi Realiti Terimbuh (AR) sebelum ini? *Have you used Augmented Reality (AR) applications before this?*				Ya / Tidak *Yes / No*
2	Berapa kerap anda menggunakan peranti mudah alih dalam sehari? *How often do you use mobile devices in a day?*				
	Tidak pernah / *Never*	Sangat jarang / *Rarely*	Kadang-kadang / *sometime*	Selalu / *Often*	Sentiasa / *Always*

C	Penilaian Kebolehpenggunaan / *Usability Evaluation*	
	Sila bulatkan jawapan anda berdasarkan skala dibawah. *Please circle your response based on the scale* below. Sangat Tidak Setuju *Strongly Disagree* ◄——► Sangat Setuju *Strongly Agree* 1 2 3 4 5	
	Kebolehfahaman / *Comprehensibility*	
1	Saya berpendapat jumlah maklumat yang dipaparkan di skrin adalah bersesuaian *I thought the amount of information displayed on screen was appropriate*	1 2 3 4 5
2	Saya berpendapat bahawa maklumat yang dipaparkan di skrin mengelirukan *I thought that the information displayed on screen was confusing*	1 2 3 4 5
3	Saya berpendapat simbol dan ikon pada skrin mudah difahami. *I thought the symbols and icons on the screen were easy to understand.*	1 2 3 4 5

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4	Saya berpendapat bahawa maklumat yang dipaparkan di skrin adalah konsisten *I thought that the information displayed on screen was consistent*	1 2 3 4 5
	Kebolehkendalian / *Manipulability*	
5	Saya mendapati peranti sukar dipegang semasa mengendalikan aplikasi AR *I found the device difficult to hold while operating the AR application*	1 2 3 4 5
6	Saya merasakan lengan atau tangan saya menjadi letih setelah menggunakan aplikasi AR *I felt that my arm or hand became tired after using the AR application*	1 2 3 4 5
7	Saya merasakan bahawa saya kehilangan cengkaman dan menjatuhkan peranti pada satu ketika *I felt that I was losing grip and dropping the device at some point*	1 2 3 4 5
	Keterlibatan *Engagement*	
8	Saya suka aktiviti itu kerana ia adalah baharu *I liked the activity because it was novel*	1 2 3 4 5
9	Saya suka jenis aktiviti tersebut *I liked the type of the activity*	1 2 3 4 5
10	Saya ingin terus menyertai aktiviti ini kerana ia menarik. *I wanted to continue participating in this activity because it was interesting.*	1 2 3 4 5
11	Saya berasa gembira dan terlibat sepenuhnya semasa menggunakan aplikasi AR. *I felt happy and fully engaged while using the AR application.*	1 2 3 4 5
12	Saya mendapati aplikasi AR mengelirukan *I found the AR application confusing*	1 2 3 4 5
	Penghayatan *Engrossment*	
13	Saya ingin tahu bagaimana penceritaan itu akan berlangsung *I was curious about how the story would progress*	1 2 3 4 5
14	Saya sering teruja kerana saya merasa menjadi sebahagian daripada penceritaan tersebut *I was often excited since I felt as being part of the story*	1 2 3 4 5
15	Sekiranya terganggu, saya tidak sabar untuk kembali ke penceritaan *If interrupted, I looked forward to returning to the story*	1 2 3 4 5

16	Saya lebih fokus pada penceritaan dan bukannya pada gangguan luaran *I was more focused on the story rather on any external distraction*	1 2 3 4 5
	Keasyikan Keseluruhan *Total immersion*	
17	Penceritaan tersebut terasa sangat asli sehingga membuat saya berfikir bahawa watak / objek maya wujud dengan nyata *The story felt so authentic that it made me think that the virtual characters/objects existed for real*	1 2 3 4 5
18	Saya merasakan bahawa apa yang saya alami terasa benar-benar mengasyikkan dan meyakinkan. *I felt that what I experienced felt completely immersive and believable.*	1 2 3 4 5
19	Saya begitu terlibat dalam penceritaan tersebut, sehingga dalam beberapa kes saya mahu berinteraksi dengan watak / objek maya secara langsung *I was so involved in the story, that in some cases I wanted to interact with the virtual characters/objects directly*	1 2 3 4 5
20	Saya begitu terlibat, dan merasakan tindakan saya boleh mempengaruhi penceritaan tersebut *I so was involved, that I felt that my actions could affect the story*	1 2 3 4 5

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Appendix C

Expert Review Form Samples for Reviewing Model



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COLLEGE OF ARTS & SCIENCES

EXPERT VALIDATION FORM VALIDATION OF CONCEPTUAL MODEL FOR ADAPTIVE AUGMENTED REALITY ADAPTING STORYTELING IN HERITAGE

I am Tenh Hock Kuan (902998), a PhD candidate from the Awang Had Salleh Graduate School at the College of Arts & Sciences, Universiti Utara Malaysia. I am working under the guidance of Assoc. Prof. Dr. Syamsul Bahrin Zaibon. The focus of the study is on developing a conceptual model known as Adaptive Augmented Reality Model adapting Storytelling in Heritage. Given your extensive academic and research background in Human-Computer Interaction, particularly in augmented reality or Mobile Applications domains, I am kindly seeking your valuable opinions, suggestions, and recommendations. Your expertise would greatly contribute to the refinement and enhancement of the conceptual model for adaptive augmented reality in heritage, especially in context of Malaysia.

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Best Regards,

Tenh Hock Kuan

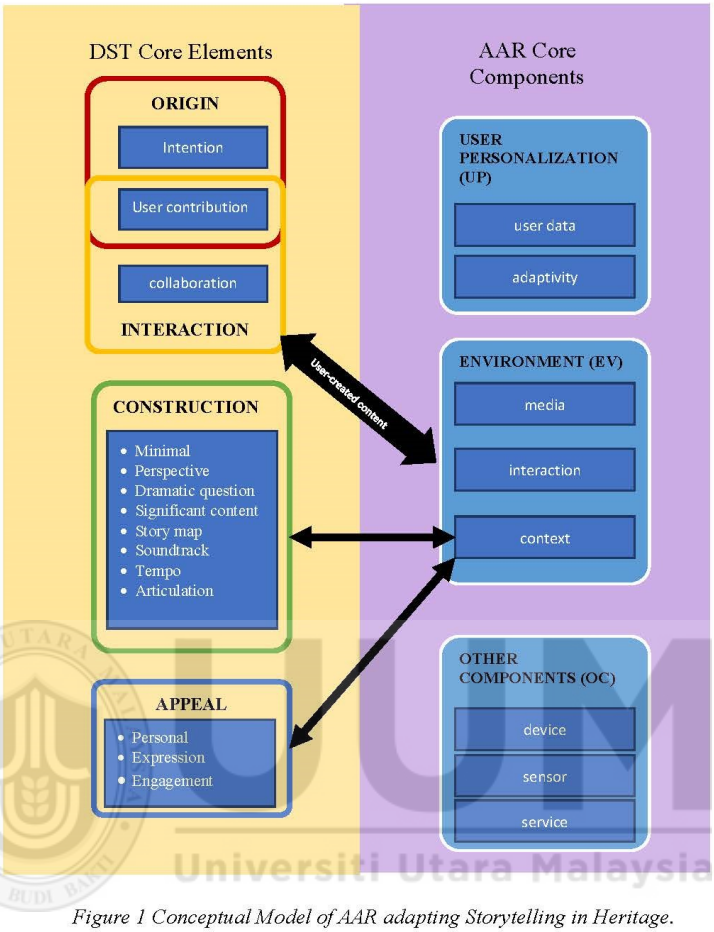


Figure 1 Conceptual Model of AAR adapting Storytelling in Heritage.

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EXPERT DEMOGRAPHIC DETAILS

1. Area of Expertise:	Computer Science, Creative Technology
2. Years of Experience:	17

EXPERT REVIEW QUESTIONS

1. Based on the conceptual model of AAR adapting Storytelling in Heritage, please tick (/) your choice.

	YES	NO
A. The proposed conceptual model of AAR is rational and understandable.	/	
B. The connection and flows for the conceptual model of AAR of all the attributes are rational.		/
C. The proposed conceptual model is practical for designing and implementing an AAR in heritage environments.	/	
D. Finally, the whole design and conceptual model is understandable.	/	

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2. Please write your further comments below, if any.

I have conducted a thorough analysis of the proposed conceptual model and have identified several areas where improvements could be made. I would like to suggest several measures that could be taken to enhance the effectiveness of the model and maximize its potential impact.

1. The current model visually indicates a relationship between DST Core Elements and AAR Core Components; however, it does not clearly articulate the nature of their integration. For example, how does user personalization within AAR impact the construction of the DST? The model could be improved by detailing specific mechanisms through which AAR components directly influence DST elements and vice versa.
2. While the model shows bidirectional arrows, indicating some feedback, it lacks explicit representation of iterative processes crucial in UX design and storytelling. The model could better reflect the iterative nature of design and storytelling, where user feedback directly informs continuous improvement of the narrative and system features.
3. The 'Other Components' section includes broad categories of 'device', 'sensor', and 'service'. The model could be refined by specifying which devices and sensors are pertinent to AAR in heritage storytelling. Furthermore, delineating the services provided could clarify their role in the user experience.
4. The 'Environment' component could be elaborated to show how different types of media, interactions, and contexts specifically adapt to the story's content and the individual user. For example, how does the model account for varying cultural or historical contexts within heritage sites? How does the AAR system adapt in real-time to changes in the environment or user behavior?

THANK YOU!!

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EXPERT DEMOGRAPHIC DETAILS

1. Area of Expertise:	HUMAN- COMPUTER INTERACTION/ INTERACTION DESIGN
2. Years of Experience:	8 YEARS

EXPERT REVIEW QUESTIONS

1. Based on the conceptual model of AAR adapting Storytelling in Heritage, please tick (/) your choice.

	YES	NO
A. The proposed conceptual model of AAR is rational and understandable.		/
B. The connection and flows for the conceptual model of AAR of all the attributes are rational.		/
C. The proposed conceptual model is practical for designing and implementing an AAR in heritage environments.	/	
D. Finally, the whole design and conceptual model is understandable.		/

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2. Please write your further comments below, if any.

I have thoroughly examined the conceptual model, and I find that its structure is a bit unclear, making it challenging to identify a clear starting point. The bidirectional arrows further contribute to confusion, as they don't clearly distinguish between dependent and independent variables. Additionally, the arrows are directed toward the environment (EV), leaving the roles of other variables, such as User Personalization and other components, unclear.
I propose considering a more explicit representation of the relationships between variables to enhance clarity. Clearly defining the direction of influence in the arrows, designating some as independent and others as dependent, can contribute to a more coherent understanding. Moreover, providing detailed explanations or labels for each variable would be beneficial to clarify their specific functions and roles within the model.

Regarding the green section representing the User Experience Design process, it may be helpful to explicitly state whether this is an integral part of the model or if it serves as the underlying research methodology. A clear rationale for its exclusion would be valuable if it's intended to be excluded.

Overall, these suggestions aim to enhance the clarity and precision of the conceptual model, ensuring that the relationships between variables are easily noticeable and the functions of each component are well-defined. I believe with some amendments; this conceptual model stands to make a valuable contribution to the academic realm.

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THANK YOU!!

EXPERT DEMOGRAPHIC DETAILS

1.	Area of Expertise:	Immersive Digital Media: Game Development, AR, VR, and Metaverse
2.	Years of Experience:	8 years

EXPERT REVIEW QUESTIONS

1. Based on the conceptual model of AAR adapting Storytelling in Heritage, please tick (/) your choice.

	YES	NO
A. The proposed conceptual model of AAR is rational and understandable.	/	
B. The connection and flows for the conceptual model of AAR of all the attributes are rational.	/	
C. The proposed conceptual model is practical for designing and implementing an AAR in heritage environments.	/	
D. Finally, the whole design and conceptual model is understandable.	/	

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2. Please write your further comments below, if any.

The model presents a clear relationship between User Experience Design Process, DST Core Elements, and AAR Core Components, offering a coherent structure.

Arrows guide the logic flow from understanding and design through storytelling components to technical implementation in AAR systems.

The modular segmentation (Origin, Interaction, Construction, Appeal, etc.) aligns well with digital storytelling theory and heritage-based immersive interaction.

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THANK YOU!!