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La réalité augmentée personnalisée pour un guidage touristique autonome.

Présentée par :

ZAIFRI Mohamed

Soutenue le 24 février 2024 devant le jury :

Nom et prénom	Etablissement	Grade	Qualité
Pr. TAIRI Hamid	Faculté des sciences Dhar El Mahraz, Fès	PES	Président
Pr. RIFFI Jamal	Faculté des sciences Dhar El Mahraz, Fès	PH	Rapporteur & Examinateur
Pr. AGHOUTANE Badraddine	Faculté des sciences, Meknès	PH	Rapporteur & Examinateur
Pr. ELANSARI Mohamed	Faculté des sciences, Meknès	PES	Rapporteur & Examinateur
Pr. ELFAZAZY Khalid	Faculté des sciences Dhar El Mahraz, Fès	PH	Examinateur
Pr. ELFAR Mohamed	Faculté des sciences Dhar El Mahraz, Fès	PH	Examinateur
Pr. ZIDANI Khalid Alaoui	Faculté des sciences Dhar El Mahraz, Fès	PES	Directeur de thèse
Pr. AZOUGH Ahmed	Pôle Universitaire Léonard de Vinci, Paris	PH	Co-directeur de thèse

Année Universitaire : 2022-2023

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Presented by:

ZAIFRI MOHAMED

Defended on February 24, 2024 in front of the jury:

Full Name	Establishment	Grade	Quality
Pr. TAIRI Hamid	Faculty of Sciences Dhar El Mahraz, Fez	PES	Chair
Pr. RIFFI Jamal	Faculty of Sciences Dhar El Mahraz, Fez	PH	Reviewer and Examiner
Pr. AGHOUTANE Badraddine	Faculty of Sciences, Meknes	PH	Reviewer and Examiner
Pr. ELANSARI Mohamed	Faculty of Sciences, Meknes	PES	Reviewer and Examiner
Pr. ELFAZAZY Khalid	Faculty of Sciences Dhar El Mahraz, Fez	PH	Examiner
Pr. ELFAR Mohamed	Faculty of Sciences Dhar El Mahraz, Fez	PH	Examiner
Pr. ZIDANI Khalid Alaoui	Faculty of Sciences Dhar El Mahraz, Fez	PES	Supervisor
Pr. AZOUGH Ahmed	Léonard de Vinci University Pole, Paris	PH	Co-Supervisor

Academic year: 2022-2023

To ”Rhita”.

Declaration

I affirm that, except where duly cited or referenced, this dissertation is entirely my original work and has not been submitted for any degree or academic award at this or any other institution. This work was conducted independently, except as acknowledged in the text and in the Acknowledgements section. This dissertation comprises less than 41,500 words, inclusive of appendices, bibliography, footnotes, tables, and equations, and contains approximately 36 figures and 20 tables.

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Abstract

Augmented Reality (AR) has emerged as a transformative concept capable of enhancing visitors' perception of the world and making the visit itself a user interface for digital interaction. Despite AR's transformative potential, the current research landscape largely adopts a "one-size-fits-all" approach to content delivery, highlighting an empirical gap in the conceptualization and evaluation of personalized AR systems. In addition, much of the existing research is geographically concentrated in Europe and Asia, creating a significant geographic gap for North African regions rich in cultural tourism. Furthermore, the limited adoption of AR in tourism is often attributed to the knowledge gap between the technology and the various tourism stakeholders. This thesis aims to reduce these research gaps by introducing and empirically evaluating FEZAR, a location-based mobile AR (MAR) application built on a novel conceptual framework for personalized, location-based AR systems. Following human-computer interaction (HCI) practices, this research includes a comprehensive literature review, the design and implementation of FEZAR, and an empirical field study to benchmark its impact on tourist engagement. The FEZAR's usability was evaluated through rigorous testing by experts in mobile technologies and AR. A comparative field study was also conducted with 40 users in the crowded Medina of Fez, revealing that the AR application significantly enhanced the visitor experience by facilitating autonomous guidance and providing informative and enjoyable experiences. This thesis reviews the evolution of AR in tourism between 2002 and 2022, analyzing 861 articles through bibliometric analysis and systematically screening the content of 57 studies. Findings illuminate a growing trend in AR research led by Europe and Asia, with the key contexts of AR application in tourism including cultural heritage, MAR, smart tourism, and emerging topics like artificial intelligence (AI), big data, and virtual tourism. AR design components frequently comprise mobile devices, marker-less tracking systems, outdoor environments, and visual overlays. This thesis provides valuable theoretical and practical implications for researchers, and stockholders in the tourism industry, shaping the discourse on the future of tourism in the post COVID-19 era. However, the experimental stage in this work is limited to the cultural and geographical context of the Medina of Fez, and focuses on visual MAR.

Keywords: Visual Augmented Reality, Personalization, Cultural Tourism, HCI, Usability, User Experience, tourism guidance.

Résumé

La réalité augmentée (RA) est apparue comme un concept transformateur capable d'améliorer la perception du monde par les visiteurs et de faire de la visite elle-même une interface utilisateur pour l'interaction numérique. Malgré le potentiel de transformation de la RA, le paysage actuel de la recherche adopte largement une approche " standard " de la fourniture de contenu, mettant en évidence une lacune empirique dans la conceptualisation et l'évaluation des systèmes de RA personnalisés. En outre, la plupart des recherches existantes sont concentrées géographiquement en Europe et en Asie, ce qui crée un vide géographique important pour les régions d'Afrique du Nord riches en tourisme culturel. En outre, l'adoption limitée de la RA dans le tourisme est souvent attribuée au manque de connaissances entre la technologie et les différents acteurs du tourisme. Cette thèse vise à réduire ces lacunes en introduisant et en évaluant empiriquement FEZAR, une application de RA mobile basée sur la localisation (RAM) construite sur un nouveau cadre conceptuel pour les systèmes de RA personnalisés et basés sur la localisation. Conformément aux pratiques d'interaction homme-machine (IHM), cette recherche comprend une analyse bibliographique complète, la conception et la mise en œuvre de FEZAR, ainsi qu'une étude empirique sur le terrain visant à évaluer son impact sur l'engagement des touristes. L'utilisabilité du FEZAR a été évaluée au moyen de tests rigoureux effectués par des experts en technologies mobiles et en réalité augmentée. Une étude comparative sur le terrain a également été menée auprès de 40 utilisateurs dans la médina très fréquentée de Fès. Elle a révélé que l'application de réalité augmentée améliorait considérablement l'expérience des visiteurs en facilitant le guidage autonome et en offrant des expériences informatives et amusantes. Cette thèse examine l'évolution de la RA dans le tourisme entre 2002 et 2022, en analysant 861 articles par le biais d'une analyse bibliométrique et en examinant systématiquement le contenu de 57 études. Les résultats mettent en lumière une tendance croissante dans la recherche sur la réalité augmentée, menée par l'Europe et l'Asie, avec les contextes clés de l'application de la réalité augmentée dans le tourisme, notamment le patrimoine culturel, la RAM, le tourisme intelligent, et les sujets émergents tels que l'intelligence artificielle (IA), le big data, et le tourisme virtuel. Les éléments de conception de la RA comprennent souvent des appareils mobiles, des systèmes de suivi sans marqueur, des environnements extérieurs et des superpositions visuelles. Cette thèse a des implications théoriques et pratiques précieuses

pour les chercheurs et les actionnaires de l'industrie du tourisme, en façonnant le discours sur l'avenir du tourisme dans l'ère post-Covid-19. Cependant, l'étape expérimentale de ce travail est limitée au contexte culturel et géographique de la Médina de Fès, et se concentre sur la RAM visuelle.

Mots-clés: Réalité augmentée visuelle, personnalisation, tourisme culturel, IHM, utilisabilité, expérience utilisateur, guidage touristique.

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Symbols

Roman Symbols

I^3 Interaction, Immersion, Imagination

R Earth Radius

T Duration

Subscripts

tsh Threshold

Acronyms / Abbreviations

6DOF Six Degrees Of Freedom

AAR Audio Augmented Reality

AI Artificial Intelligence

AR Augmented Reality

AV Augmented Virtuality

CH Cultural Heritage

FEZAR Fez Augmented Reality

FOV Field Of View

HCI Human Computer Interaction

HMD Head Mounted Device

IoT Internet of Things

MAR Mobile Augmented Reality

MR Mixed Reality

PAR Personalized Augmented Reality

POI Point Of Interest

PRISMA Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SLAM Simultaneous Localization And Mapping

UI User Interface

UX User Experience

VAR Visual Augmented Reality

VE Virtual Environment

VR Virtual Reality

XR Extended Reality

Chapter 1

Introduction

1.1 Context of the Thesis

1.1.1 Emergence of Augmented Reality (AR)

Augmented Reality (AR), a variant of virtual environments (VE) that allows users to see the real world with virtual objects overlaid in real time (Azuma et al., 2001), has emerged as a transformative tool with significant promise to revolutionize various sectors including education, medicine, gaming, and notably, tourism (Manuri and Sanna, 2016). AR and virtual reality (VR) are being implemented in various tourist and hospitality areas, such as theme parks, museums, historical sites, tourism education, etc. (Wei, 2019). Contrary to VR, which creates an entirely computer-generated experience immersing users into an artificial world, AR overlays virtual objects onto the real world, creating an overlapping reality where the two coexist seamlessly (Azuma et al., 2001; Feng Zhou et al., 2008). These technologies have gained significant attention from researchers and practitioners, due to their capability to enhance tourists' satisfaction, by delivering unforgettable experiences (Loureiro et al., 2020). AR expands the visitor experience to new dimensions, enriching their engagement with cultural attractions while maintaining their connection with the actual surroundings (Park and Stangl, 2020).

1.1.2 Tourism 4.0

As illustrated in Figure 1.1, which presents a historical overview of digital empowerment in tourism from Tourism 0.0 to Tourism 4.0, the journey of digitization and reinforcement in the tourism industry traces back to the advent of the Internet. Tourism 4.0, the latest phase in this evolution, is a convergence of emerging technologies, inspired by the principles of

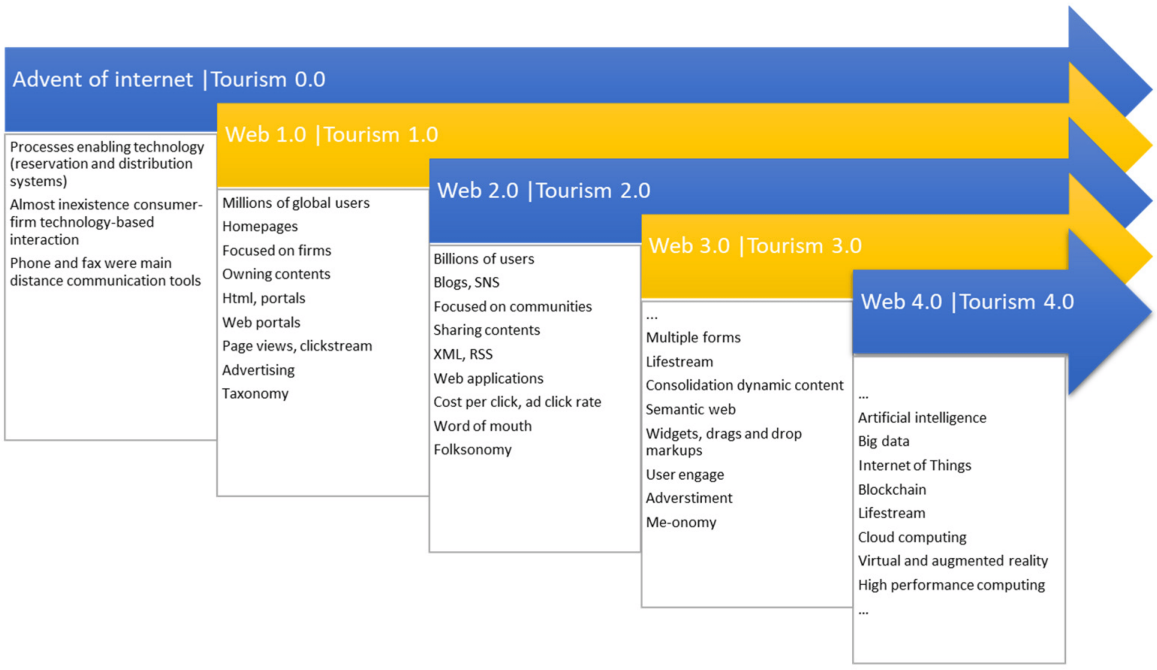


Fig. 1.1 Digital empowerment in tourism by (Borges-Tiago et al., 2021)

Industry 4.0, including Artificial Intelligence (AI), Big Data analytics, the Internet of Things (IoT), Blockchain, AR and VR. These technologies are being strategically integrated into the tourism sector with the primary objective to enhance the overall visitor experience and address various industry challenges (Kindzule-Millere and Zeverte-Rivza, 2022).

Global perspective

The tourism sector is facing numerous challenges related to technology, economics, and sustainability (Loureiro and Nascimento, 2021). The COVID-19 pandemic has further intensified these challenges, causing significant socio-cultural and economic impacts on various stakeholders in the industry, with some effects expected to persist for years to come (Sigala, 2020). On the bright side, it has also led to increased use of technology in tourism, with more businesses moving towards digitization.

In addition, with the rapid development of mobile technology, and the emergence of groundbreaking AR applications, such as the Pokémon Go craze (Laine, 2018), tourists are showing an increasing demand for AR-enabled travel experiences (Mohanty et al., 2020).

Local context

As one of Morocco's most vital economic pillars and a key driver for social development, tourism occupies a central role. The country is home to nine UNESCO World Heritage sites, highlighting its rich cultural heritage and global importance. One of these prestigious sites is the ancient Medina of Fez, located in northern Morocco. Designated a UNESCO World Heritage Site in 1981[1], the Medina attracts international tourists, drawn by its complex mix of religious, civil and military monuments. Its complex network of narrow, winding alleys and busy neighborhoods gives the impression of a crowded open-air museum. However, this cultural treasure faces a number of threats. These include human and environmental factors such as overpopulation and urban degradation.Tourists in the Medina usually find themselves reliant on basic maps or non-targeted GPS systems to make their way through the complexe layout. Moreover, the cultural insights offered are generally restricted to standard brochures and formal guides, falling short of providing a fully enriching experience. The combination of these factors tends to compromise the visitor's experience, underscoring the urgent need for inventive solutions that are specifically designed to cater to the local context.

1.1.3 The Potential of AR in Tourism

Pioneering studies, such as that by Vlahakis et al. (2001), have introduced novel systems that offer AR tours and 3D reconstructions of ruined historical sites. Additionally, advancements in AR technology, as highlighted by Höllerer and Feiner (2004), have enabled tourists to easily discover destinations, access background information, and explore countless possibilities, limited only by the capabilities of the AR device, and the available information. Since then, AR has been increasingly adopted to provide tourists with relevant information about the sites they visit, improve navigation, and create highly dynamic experiences at tourist attractions (Kounavis et al., 2012).

The potential of AR in tourism has garnered significant attention from researchers in recent years, leading to a surge in projects and proofs of concept that demonstrate how AR technology is utilized to enhance the tourist experience in various cultural settings (Zaifri et al., 2023a). Along with this trend, personalized recommender systems have become increasingly prevalent in the tourism sector due to mobile technology advancements (Fararni et al., 2021). Nevertheless, the body of research focused on personalized AR systems and experiences, while growing, is still relatively scarce and represents a valuable avenue for further exploration. On the other hand, many governments around the globe have recognized the potential of Tourism 4.0 and have launched initiatives to transform the tourism industry

[1] https://whc.unesco.org/fr/list/170/

using the augmented reality technology. Examples include Malaysia 4.0 (Basir et al., 2022) and Slovenia Tourism 4.0 (Urbančič et al., 2020).

Location-based mobile AR technology offers several advantages for users, including the ability to display real-time information on the user's location and points of interest , as well as the option to display virtual images simultaneously with real-world images, which was found to be highly valued by users (Chen, 2014). It can also integrate content from various social networks to enhance awareness of the visited region (Demir and Karaarslan, 2018) and provide a more user-friendly interface, simplifying the search for historical locations.

1.2 Research Approach

The research methodology employed in this thesis adheres to established HCI (Human-Computer Interaction) practices, similar to the work presented by Pucihar (2015). Initially, the work commences with a thorough literature review to synthesize existing knowledge on the subject. Following this, a proof-of-concept system is designed to address the posed research questions. This system serves as the basis for the experimental phase, where data is collected through empirical study and analyzed to either validate or reject the research hypotheses.

1.3 Research Questions

The primary objective of this work is to study how personalized, visually-oriented augmented reality affects the tourist experience—a concept that itself is complex and varies based on tourist needs and the services offered. Specifically, we look at the role of location-based visual AR in enhancing the quality of navigation and guidance within the context of cultural tourism. We seek to determine if such AR solutions could serve as a foundation for self-guided tourism in the near future. To achieve this primordial goal, we have segmented our objective into sub-goals, each addressing different research gaps identified in this thesis.

- Firstly, we aim to trace the trajectory of AR within the tourism industry, starting from its initial explorations in 2002, up to its more sophisticated applications in 2022. Our goal is to offer a comprehensive overview of the developmental arc, contexts of application, and design elements integral to AR in tourism. In doing so, we seek to identify existing research gaps and pinpoint avenues for future exploration. To guide this portion of our research, we pose the following research questions:

(**RQ1):** How are research articles on AR in tourism distributed temporally and regionally over the period (2002–2022)?

(**RQ2):** What are the main contexts in which AR research was used to support the tourism industry, and how has this evolved over time?

(**RQ3):** What are the most commonly used AR design components (systems, devices, virtual content, tourism settings), and how do they integrate to enhance the tourism experience?

- Second, we present FEZAR (FEZ Augmented Reality), a mobile prototype that utilizes location-based visual AR techniques to serve as an outdoor tour guide. Built upon a novel conceptual framework for personalized, location-based AR systems, FEZAR utilizes both the user's context and behavioral patterns to anticipate interests, subsequently recommending a personalized itinerary for cultural heritage site tours. In this scope, the following research questions are addressed:

  (**RQ4):** How can the user's preferences and behavior be captured and incorporated into the design of a personalized location-based AR interface for tourism?

  (**RQ5):** What key features of a personalized location-based AR interface in tourism could improve the user's experience?

- Finally, our objective is to empirically examine the role of mobile augmented reality in aiding tourists as they navigate through crowded destinations. At this stage, we intend to conduct a comparative field study that compares the effectiveness of FEZAR against conventional applications, with the aim of collecting data to either validate or refute our research hypotheses. The research questions for this segment are formulated as follows:

  (**RQ6):** How does the use of a visual MAR application compare to conventional methods in enhancing both the enjoyment and usability during a tourist visit?

  (**RQ7):** Does the MAR application facilitate easier navigation and access to tourist information concerning historical landmarks compared to traditional navigation methods?

The questions addressed in this work fall into several disciplines, including augmented reality, HCI, user experience, geolocation, and tourism mediation, as illustrated in Figure 1.2.

1.4 Thesis Outline

In this chapter (**the first chapter**), the context and motivation behind this thesis are outlined, along with the research questions we aim to answer to bridge the existing knowledge gap. the rest of the thesis is structured as follows :

In **the second chapter**, we establish the foundations and scope of the contributions we have made through our analysis of research gaps. We begin the chapter with an in-depth look at the definition and history of augmented reality (AR), contextualized within a visual framework. We then explain what we mean by "mobile AR" and detail the operational mechanisms of vision-based AR. In this chapter, we also highlight the main emerging concepts and trends of AR in the tourism industry, highlighting its most recent applications. In addition, we look at personalized AR, giving an overview of how AR can be customized to individual user experiences. In conclusion, we discuss the wide range of methods for evaluating the AR interface, tracing the evolution of these techniques in the field of HCI.

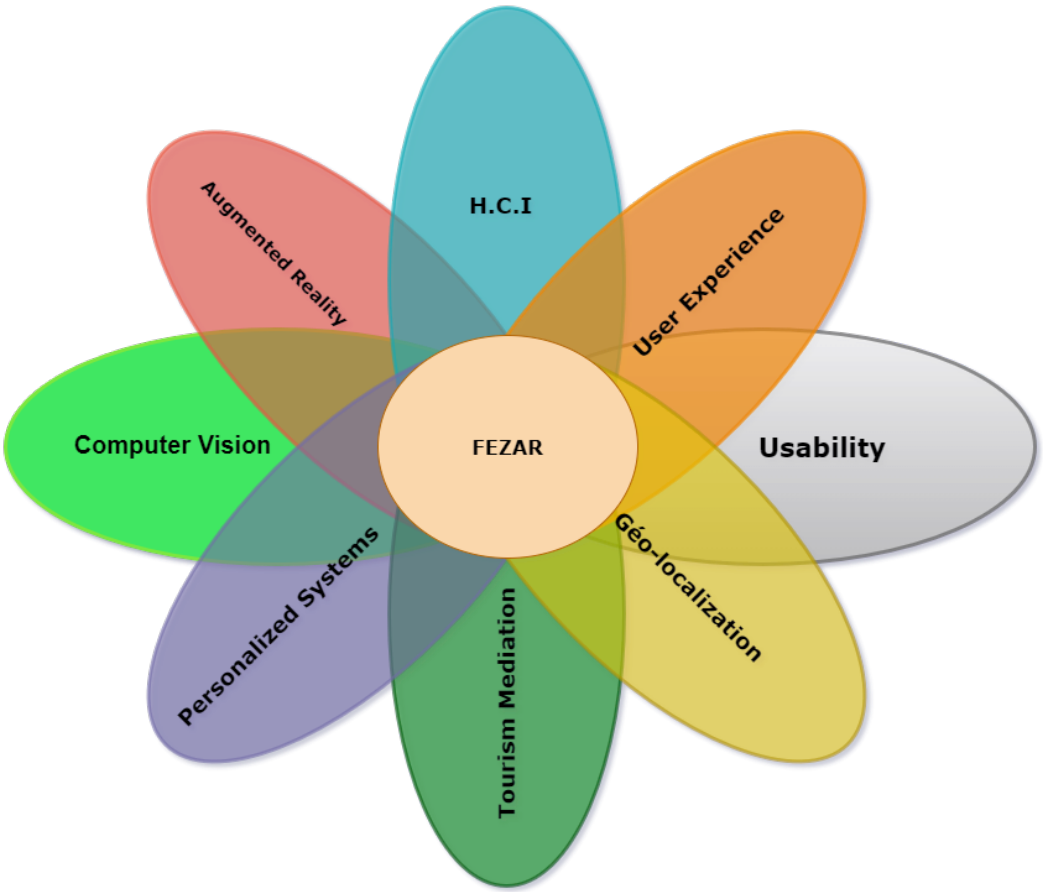


Fig. 1.2 Disciplines concerned by this work

In **the third chapter**, we provide a comprehensive review of the existing literature on the application of augmented reality in the tourism sector, spanning two decades from 2002 to 2022. In this chapter, both bibliometric and systematic content analyses were employed to reveal the progress, application settings, and potential future avenues of augmented reality in the tourism industry. Moreover, it identifies the design elements (i.e. AR tracking systems, AR devices, Tourism settings, virtual content) of augmented reality that are most frequently employed to amplify the tourist experience. The chapter intends to inform researchers, industry practitioners, policymakers, and educators about the current state of the field, potential research directions, and practical implications. In other words, the chapter points out where, when, and how is AR being implemented to support the tourism experience.

In **chapter four**, we present FEZAR, a personalized mobile augmented reality prototype designed to guide tourists in outdoor environments. Serving as a tangible proof of concept, FEZAR is the focal point of this thesis. In this chapter, we explore the complexities of FEZAR's design and the process of its implementation, establishing it as the technological framework we use to empirically validate our hypotheses.

The **fifth chapter** describes the experimental dimension of this thesis. Here, the FEZAR model is empirically evaluated in a real tourist visit scenario against existing conventional solutions in order to analyze user performance using a comparative field method preceded by a usability assessment. This chapter demonstrates the empirical evaluation approach and illustrates interesting results that help to understand the impact of augmented reality on the tourism experience, particularly in the case of crowded destinations.

In **the final chapter**, we draw conclusions and summarize the thesis' key findings, while also identifying exciting opportunities for subsequent research. Future work may include exploring AI integration and diverse modalities of AR, such as gustatory AR in food tourism.

1.5 List of Publications

Most sections of this thesis have been published in various scientific journals and conferences, a brief overview of which is provided below. Other sections are currently undergoing a peer-review process.

Journal Articles

- Zaifri, M., Khallouf, H., Kaghat, F.Z., Benlahbib, A., Azough, A., Zidani, K.A. (2023). "Enhancing Tourist Experiences in Crowded Destinations through Mobile Augmented Reality: A Comparative Field Study". International Journal of Interactive Mobile Technologies (iJIM), 17(20), pp. 1–22. https://doi.org/10.3991/ijim.v17i20.42273

- Zaifri, M., Khallouf, H., Kaghat, F.Z., Azough, A., Zidani, K.A. (2023). "From Earlier Exploration to Advanced Applications: Bibliometric and Systematic Review of Augmented Reality in the Tourism Industry (2002–2022)". Multimodal Technologies and Interaction (MTI) 7(7): 64. https://doi.org/10.3390/mti7070064

- Zaifri, M., Khallouf, H., Kaghat, F.Z., Benlahbib, A., Azough, A., Zidani, K.A. "Personalized Location-based Augmanted Reality for Cultural Tourism Tours based on User Behavior: a Conceptual Framework". IEEE ACCESS. (SUBMITTED)

Conference Papers

- Zaifri Mohamed, Ahmed Azough, and Said Ouatik El Alaoui. "Experimentation of visual augmented reality for visiting the historical monuments of the medina of Fez." In 2018 International Conference on Intelligent Systems and Computer Vision (ISCV), pp. 1-4. IEEE, 2018. https://doi.org/10.1109/ISACV.2018.8354051, Fez, Morocco.

Posters

- Zaifri Mohamed, Ahmed Azough, and Said Ouatik El Alaoui. "Experimentation of visual augmented reality for visiting the historical monuments of the medina of Fez." In 2nd edition of the national symposium signal, image, multimedia and applications (SIGMA) April 17-18, 2018, Rabat, Morocco.

Chapter 2

Background on Augmented Reality

2.1 Introduction

In the era of the fourth industrial revolution[1] (Industry 4.0), augmented reality (AR) is being integrated as an emerging technology to support Tourism 4.0 (Kindzule-Millere and Zeverte-Rivza, 2022), where it enhances visitors' perception of the world, enriching their experiences through interactive interfaces and promoting the tourism offer. Understanding the background of this transformation, and how the research community is applying AR in Tourism is a crucial task.

This chapter defines the key concepts used in this thesis, explores the role of AR in the transformation of Tourism, and presents a comprehensive review of previous and related work to the thesis. It provides the fundamental understanding needed to contextualize our research within the existing knowledge landscape.

This chapter is organized as follows : Section 2 traces the definition and historical development of AR, highlighting the distinction between AR and VR (Section 2.2). Building on this foundational knowledge, Section 3 introduces the concept of mobile AR (MAR), explaining its transition from the mobility of AR experiences to a handheld AR experience (Section 2.3). Section 4 provides an overview of visual AR, covering the processes involved in "vision augmentation" and the various display devices that enable it (Section 2.4). In Section 5, we examine current trends in AR applications dedicated to tourism, highlighting the main patterns and implementations of AR in this field (Section 2.5). Personalization, a crucial element of modern digital experiences, is the subject of Section 6, in which we explore the notion of personalization and review the landscape of personalized AR systems in tourism (Section 2.6). Section 7 is reserved for the evaluation of AR interfaces. This section

[1]The Fourth Industrial Revolution: What It Means and How to Respond. @FOREIGN AFFAIRS : https://www.foreignaffairs.com/world/fourth-industrial-revolution

not only reviews the different studies that incorporated AR evaluation in the tourism context; but also summarizes the various types and methods used (Section 2.7). Finally, in Section 8, we identify and analyze gaps in existing research, based on the literature review carried out in this chapter, to highlight areas that require further study and development (Section 2.8).

2.2 Augmented Reality

2.2.1 Terminology

Personalized augmented reality is a combination of the words "personalized", "augmented" and "reality". The etymological definitions of the three terms, as presented in the Oxford Dictionary, are as follows:

- "Personalized": *adjective*. Designed or changed so that it is suitable for the needs of a particular person.
- “Augment”: *verb*. To increase the amount, value, size, etc. of something.
- "Reality": *noun*. (Plural: realities). 2. [countable] A thing that is actually experienced or seen, in contrast to what people might imagine.

From these definitions, various elements can be directly interpreted:

- The augmentation of Reality consists of increasing the user’s perception level of a scene experienced or viewed, by overlaying additional digital information or elements onto the real-world environment.
- Augmented reality aims to increment the perceived content, enriching the user’s sensory or informational experience within a given environment.
- Personalized augmented reality occurs when the augmentation is customized to meet the unique needs or preferences of the user, thus fostering a customized interaction between the individual and the augmented reality experience.

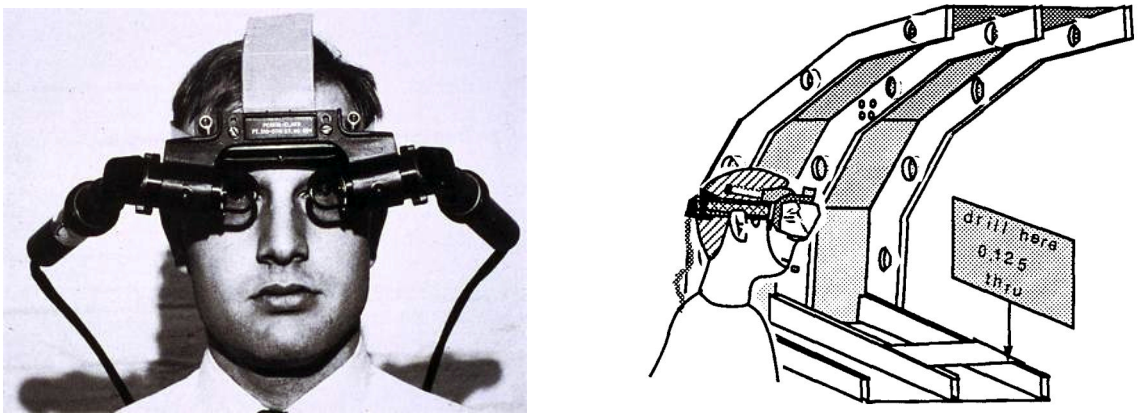
In addition, the Oxford Dictionary defines augmented reality as follows:

- "Augmented Reality": *noun*. (*abbreviation* AR). [uncountable] a technology that combines computer-generated images on a screen with the real object or scene that you are looking at.

This simplistic description is a good introductory definition for those unfamiliar with the concept. It highlights the integral aspect of AR, namely the merging of digital imagery with the user's vision of the real world.

However, for a more nuanced or technical discussion on the definition of AR, Section 2.2.2 reviews the various definitions proposed by the research community in the literature.

2.2.2 History and Definitions



(a) (b)

Fig. 2.1 (a): The head-mounted display optics with miniature CRT's by Sutherland (1968). (b): The "*HUDset*" implemented by Caudell and Mizell (1992) is used to dynamically mark the position of a drill/rivet hole inside an aircraft fuselage.

While the term "augmented reality" was initially coined in 1992 by Caudell and Mizell (1992) to describe the overlay of computer-generated content on the real world as depicted in Figure 2.1b, the concept can be traced back nearly 50 years in the works of Sutherland (1968) in 1968. As shown in Figure 2.1a, Sutherland introduced a head-mounted 3D display with the objective of immersing the user in a three-dimensional informational environment.

The genuine surge in this domain was initiated in the 90s, starting with the pioneering work of Bajura et al. (1992), followed by State et al. (1996). Their groundbreaking works aimed at providing physicians with the ability to visualize ultrasound imaging data directly on the patient's body, thereby enhancing the perceptual experience. As it has evolved, AR has expanded its horizons, covering a wide range of applications, from medicine and engineering/production to architecture, robotics, and entertainment, as highlighted in Azuma's survey (Azuma, 1997).

Milgram et al. (1995) initiated the discussion on the definition of augmented reality in 1994 after observing that researchers were frequently utilizing the term "augmented reality"

without accompanying it with a clear definition. Consequently, Milgram et al. presented their definition of augmented reality as *the set of cases in which a real environment is augmented by computer-generated virtual objects*. Nonetheless, this definition does not clarify "how" the real environment is augmented, nor does it specify the nature of the relationship between the real and virtual worlds.

According to Baudel (1995), "*augmented reality aims to 'augment' the properties of the objects in our environment with information-processing capabilities. In addition to their material (ergotic) function, they acquire a computational (semiotic) dimension, through their ability to react not only to the physical phenomena to which they are subjected, but also to the information they capture about the state of their surroundings (people, environment, other "augmented" objects...).*"

Bowskill et al. (1997) posits that *augmented reality is seen as a means of augmenting the user's senses, transforming imperceptible events into visible, audible, or touchable phenomena. It is seen as a symbiosis between man and machine like never before.* While this definition provides a generalized perspective, it lacks clarity on how the augmentation transpires.

To overcome this limitation, Mackay (1996) has distinguished three types of augmentation:

- Augmentation of the user: through a device worn by the user on the head (HMD) or on the hand (handheld).
- Augmentation of the physical object: the physical object is modified by incorporating input or output devices on it.
- Augmentation of the environment: independent devices provide and collect information from the environment, displaying information about objects and capturing information about the user's interaction with them.

In this context, Mackay defines augmented reality as *a way of reintegrating "electronic information into the physical world". It is about "enabling people to leverage their skills in interacting with the everyday world, while taking advantage of the power of computer networks".*

A less restrictive definition is proposed by Fuchs and Moreau (2003): "*augmented reality encompasses all techniques for associating a real world with a virtual world, especially by using the integration of real images with virtual entities: computer-generated images, virtual objects, texts, symbols, diagrams, graphics, etc.*". Other types of association between real and virtual worlds are possible through sound or force feedback. Nonetheless, This definition does not profile the type of association between the real and virtual worlds.

To address the shortcomings highlighted in previous definitions, Ghouaiel (2014) proposed the following definition: "*Augmented reality is the combination of sensory data with the real world in such a way that, pursuing a well-defined purpose, they appear to coexist with and be linked to the real world.*" This definition therefore highlights the aspects of multi-modality, non-restrictivity, the link between the real and virtual, and the purpose of the real-virtual combination.

The most adopted, structured, and widely recognized definition of augmented reality is that of Azuma (1997), who articulated a definition not tied to any particular technique. According to them, augmented reality is any system that possesses three characteristics:

1. Combination of real and virtual aspects: 3D virtual objects must be integrated into the real world.

2. Real-time interactivity: the system must enable the user to interact with virtual objects in real-time.

3. Three-dimensional registration: This enables virtual objects to be aligned with real objects so that they appear to coexist in the same space as the real world.

In this thesis, we depict virtual objects as 3D images and align them with tourist attractions based on their geometric coordinates. Our system effectively enables users to interact with these virtual objects through mobile devices on smartphones or tablets.

2.2.3 Extended Reality (XR): AR *vs.* VR

Virtual reality (VR) also has its roots dating back to 1962 when Heilig (1962) secured a patent for a concept named "Sensorama". This pioneering VR video device enabled users to experience pre-recorded vibrations, sounds, scents, and wind. Since the 1990s, with the advancement of computer graphics science, VR has emerged as a prominent topic. The progression of VR technologies now allows users to be fully immersed in a wholly artificial environment. This development sparked a broad discussion regarding the relationship or distinction between AR and VR.

In the quest to establish a relationship between AR and VR, Milgram and Kishino (1994) introduced a linear continuum spanning the real and virtual worlds, termed as mixed reality (Figure 2.2). Within this continuum, AR resides near the real environment, while Augmented Virtuality (AV) is situated closer to the virtual environment, where most of the user's view is replaced by computer-generated images, but where a view of the real world remains. In this scenario, Milgram and Kishino agree that AR and VR are interconnected concepts, and it is valid to consider them together as lying at opposite ends of a one-dimensional continuum.

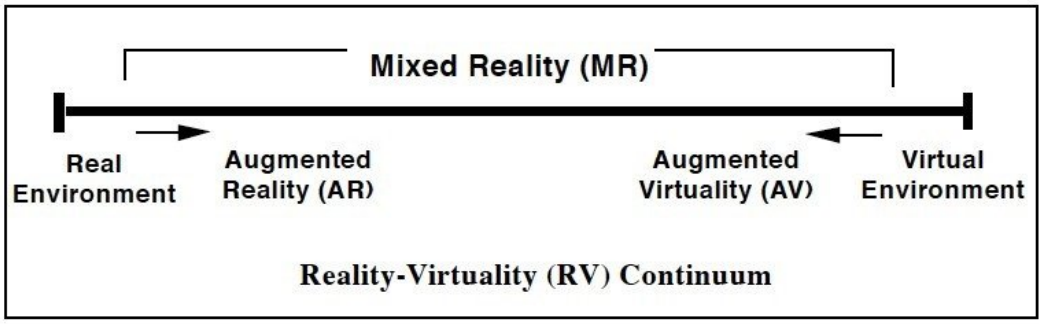


Fig. 2.2 The linear continuum of Milgram and Kishino (1994)

Billinghurst et al. (2015) describes the distinction between AR and VR based on the core objectives of both systems. They suggested that a VR system's chief aim is to utilize technology to replace reality, creating a fully immersive experience. In contrast, an AR system primarily seeks to amplify reality by infusing it with digital content in a non-immersive manner. This perspective also invites a comparison of the two technical modalities through the prerequisites for each of them, as illustrated in Table 2.1.

Table 2.1 VR and AR technology requirements. Adapted from Billinghurst et al. (2015)

	Virtual Reality	Augmented Reality
Main Purpose	Replacing reality	Augmenting reality
Scene Generation	Realistic images	Minimal rendering
Display Device	Fully immersive	Non-immersive
Field Of View (FOV)	Wide	Small
Tracking and Sensing	Low accuracy	High accuracy

Dubois (2001) integrates the paradigms of AR and VR by introducing an AR triangle that parallels Burdea and Coiffet (1994)'s VR triangle depicted in Figure 2.3. He advocates for a redefinition of the I^3 representation (Interaction, Immersion, and Imagination) —used as a VR symbolic — replacing the terms with interaction, enrichment, and real-world for AR systems (see Figure 2.4).

Dubois et al. (1999) introduced a taxonomy that distinguishes between AR and VR based on two distinct concepts: task object and augmentation type. The task object can either be a real entity, implicating AR as a "quantity" of virtual added to real, or a virtual entity, signifying AV as a "quantity" of real added to virtual (see Figure 2.5).

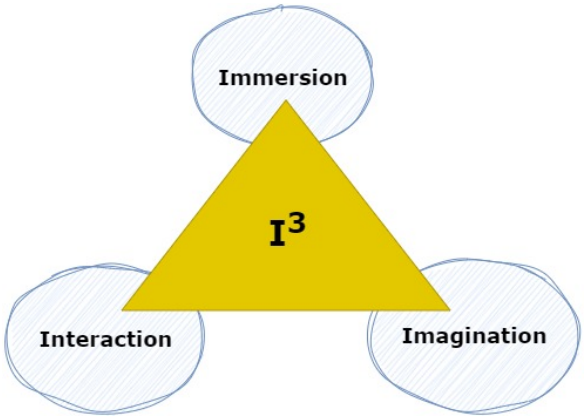


Fig. 2.3 Virtual Reality Triangle of Burdea and Coiffet (1994) in 1994.

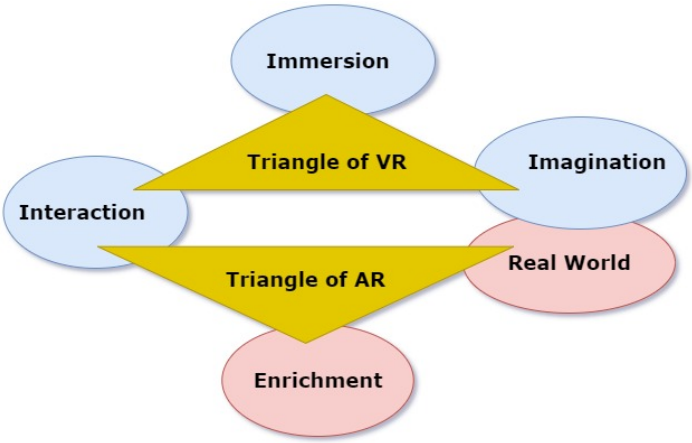


Fig. 2.4 AR and VR triangles of Dubois (2001) in 2001.

The commonly accepted notion of a VR environment posits that the user is fully immersed in a synthetic universe, which might either replicate the attributes of a real setting or be fictitious. On the other hand, as noted in Section 2.2.2, AR is typically viewed as overlaying virtual 3D elements onto the real world. As a consequence, while the user's perception is augmented, they remain connected to the real world and aren't isolated from it. Thus, in a real, physical situation of user navigation and orientation, VR stands apart and differs greatly from AR due to the mobility of the user in physical space and the constant shifting of point of view (Al Rabbaa et al., 2019).

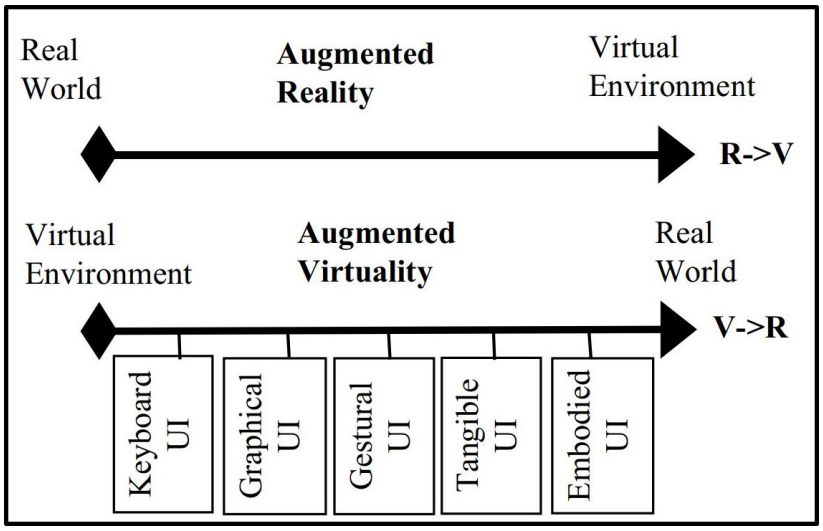


Fig. 2.5 Illustration of the task object: entities set on the left and expanded to the right, based on a range of interaction metaphors.

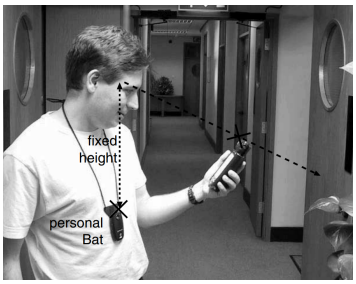
2.3 Mobile Augmented Reality (MAR)

In this thesis, we present a mobile augmented reality (MAR) model called FEZAR. For the purpose of clarity throughout this document, it is essential to precisely define the term "mobile AR". This specification is intended to avoid ambiguity in subsequent chapters.

In their paper, Arth et al. summarized the history of AR between 1968 and 2014 (Arth et al., 2015). They found that as MAR evolved over time, two major and different interpretations were considered. The first case of MAR can be associated with the development of



(a) Touring Machine prototype by Feiner et al. (Feiner et al., 1997)



(b) BatsPortal prototype on PDA by Newman et al.(Newman et al., 2001)



(c) Video see-through AR prototype on a cell-phone, by Mohring et al. (Mohring et al., 2004)

Fig. 2.6 The evolution of MAR concept over time, from wearable AR to handheld AR.

wearable AR, in the context of experiencing AR during locomotion (mobile as mobility). This categorization would naturally include HMDs as a form of MAR. With the miniaturization of physical devices and displays, the idea of mobile AR has shifted to the concept of "mobile device", i.e. AR experience on a handheld device (mobile as handheld), including gadgets such as PDAs, mobile phones, and tablets.

In 1997, Feiner et al. introduced the “Touring Machine” (Feiner et al., 1997), recognized as the first mobile augmented reality system (MARS). This system incorporated a see-through HMD equipped with an inbuilt orientation tracker (see Figure 2.6a). A backpack carried the computer, differential GPS, and a digital radio for wireless internet access, complemented by a handheld device that operated with a stylus and touchpad. In this context, MAR highlights the system’s portability, enabling users to engage with AR while on the move. Consequently, in this era, MAR is primarily defined by the system’s ability to support dynamic interactions in different locations and scenarios.

In 2001, Newman et al. introduced the BatPortal (Newman et al., 2001), a PDA-integrated wireless AR system, as illustrated in Figure 2.6b. The system locates the user’s position by measuring the duration of ultrasonic pulses traveling between unique devices, known as Bats, worn by the user and stationary receivers installed across the building’s floors and ceilings. Subsequently, a scene model, complemented with additional data about the environment, is displayed on the PDA’s screen. Three years later, Möhring et al. introduced a method for tracking 3D markers using a mobile phone (Mohring et al., 2004), as depicted in Figure 2.6c. This research demonstrated the first video see-through augmented reality system implemented on a standard consumer cell-phone. The system is capable of recognizing various 3D markers and seamlessly integrates rendered 3D graphics into the real-time video feed. The introduction of such systems marks the migration of the research community to the new definition of MAR as AR on a hand-held device.

Höllerer and Feiner (2004) pinpointed six essential components that are fundamental in defining a mobile augmented reality system:

1. A mobile computational platform.
2. A mobile display device.
3. A System for tracking and registration.
4. Interaction tools, including wearable inputs.
5. Wireless connectivity.
6. Technologies for data access and storage.

Handheld displays present a suitable replacement for HMD systems in AR applications. Their benefits include being less obtrusive, socially accepted, easily accessible, and highly portable. Presently, various mobile devices, such as tablet PCs, smartphones, and PDAs, serve as platforms for mobile AR experiences (Feng Zhou et al., 2008). In our thesis, the mobile AR system we introduce adheres to the more recent definition of mobile AR as a handheld system.

2.4 Visual Augmented Reality (VAR)

As previously stated, an AR system involves overlaying virtual objects within the real world, enabling them to coexist in physical space and permitting the user to interact with these objects in real-time. This not only enhances the user's perception of the real world but also transforms the physical environment into an interaction interface. Visual Augmented Reality (VAR) encapsulates the idea of amplifying the user's visual perception (Bonnet, 1988). VAR, therefore, encompasses the techniques utilized to expand the user's vision by overlaying computer-generated visual objects, which could be in the form of 2D entities (such as images, text, textures, etc.) or 3D models, onto the real world.

We'll start by giving an overview of the fundamentals and steps involved in realizing a visually augmented reality. Next, we'll look at hardware solutions that facilitate the execution of the VAR systems.

2.4.1 The Augmentation of Vision

To better understand the requirements of vision-based augmented reality (VAR), it is imperative to immerse ourselves in its operating mechanisms. As shown in Figure 2.7, The fundamental operating principle of vision-based augmented reality can be described in 5 main steps (blue blocks) as follows:

1. **Scene recognition** : Before any augmentation can take place, the AR system needs to identify,recognize, and understand its surroundings, in which the AR system is deployed. This is the foundational step for any AR system. Modern AR frameworks are increasingly turning to hybrid deep models, exploiting the strength of machine learning and deep neural networks, to accurately recognize their surroundings using stored images or 3D models (i.e. Marker-Based) (Xie et al., 2020). In many markerless AR setups, natural features serve as the basis for linking successive images in a video sequence (Skrypnyk and Lowe, 2004). An integral technique in this field is SLAM (simultaneous localization and mapping), which becomes essential when

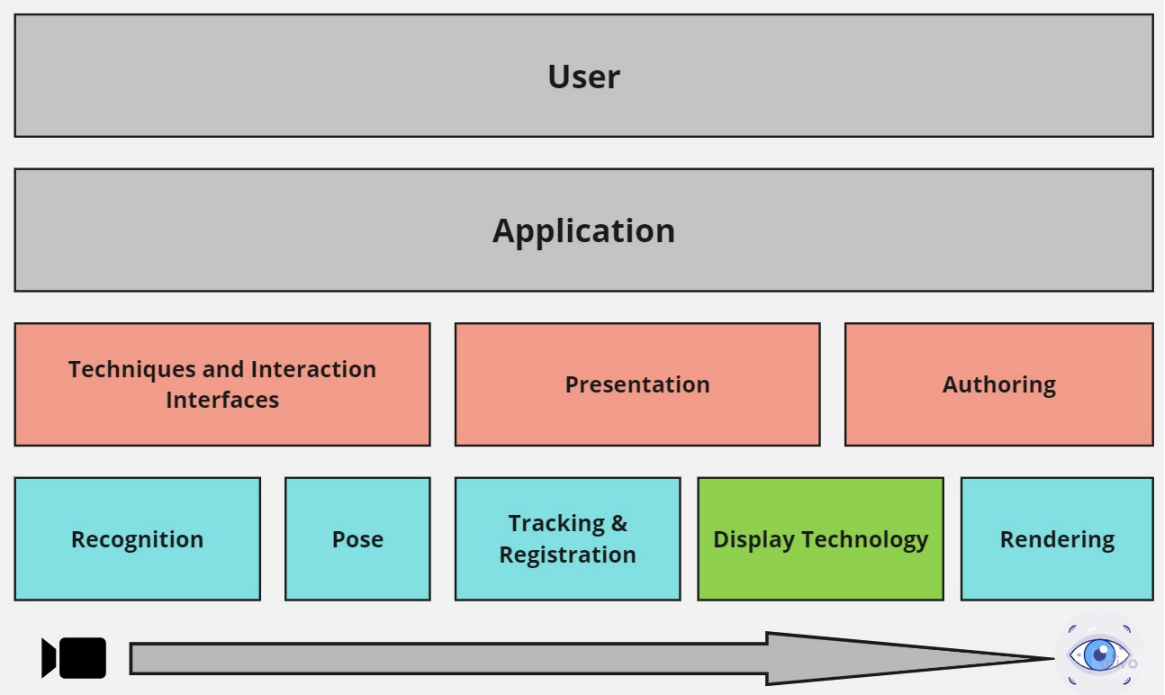


Fig. 2.7 Technological building blocks of an AR system. Modified from (Ghouaiel, 2014)

mapping the 3D contours of an unknown spatial location (Taketomi et al., 2017). When this method relies solely on camera-based visual cues, it is called vSLAM (Visual SLAM). Table 2.2 presents a detailed juxtaposition of these AR scene recognition methodologies, highlighting their respective strengths and challenges.

2. **Pose estimation** : After the scene recognition, the system determines the 'pose', which refers to the spatial position (3D translation) and orientation (3D rotation) of an object, most commonly a camera, relative to a known environment or a specific marker. The SLAM techniques utilize algorithms such as ORB-SLAM and PTAM to continuously refine the pose estimation while simultaneously creating a map of the environment (Taketomi et al., 2017). This could explain why vSLAM have become more popular for AR frameworks. Mathematically, the camera pose is represented by a 3×4 matrix, denoted as $[R|t]$, which captures the six degrees of freedom (6DOF) intrinsic to it. Within this matrix, R is a 3×3 matrix representing the camera's rotation (roll, pitch, and yaw). Meanwhile, t is a 3×1 vector that depicts the camera's translational movements along the x, y, and z axes. The derivation of R and t necessitates the use of pairs of 3D points in the real world and their corresponding 2D projections in the image. This relationship is often framed as the Perspective-n-Point (PnP) problem. A notable solution to the PnP problem is the '*solvePnP*' function available in OpenCV, a

widespread computer vision library [2]. Furthermore, various research, such as that by Lu (2018), delves deeper into the details and solutions of the PnP problem.

3. **Tracking** : Having determined the camera's pose, the AR system's understanding of the environment should remain updated as the camera moves or as objects within the environment change, this ongoing process is called Tracking. This involves monitoring key features or markers and updating their position in real-time. Tracking systems are categorized according to the technology or the nature of the sensor. Billinghurst et al. (2015) have shown in their extensive survey a wide variety of tracking approaches that have been used in the literature including magnetic, vision-based, inertial, GPS, and hybrid tracking approaches. Modern systems often utilize hybrid tracking solutions, combining visual data with inertial sensors to improve the difficulties posed by general indoor and outdoor mobile AR systems (Van Krevelen and Poelman, 2010). In the literature, distinctions between the two terms "Registration" and "Tracking" are often vague. More often than not, the term "Tracking " is used to merge the two concepts.

4. **Registration** : This process ensures that the virtual content aligns correctly with the real-world view of the user. It matches the coordinates of the virtual and real environments so the rendered AR content appears in the right place. Vision-based registration methods for AR are subject to difficult conditions, such as an expanded working scene, changing lighting, sudden movements, and occlusion (Guan and Wang, 2009). Calibration techniques are often employed to improve the accuracy of registration (Skrypnyk and Lowe, 2004). Table 2.3 provides a categorization and analysis of the registration techniques employed in AR studies.

5. **Rendering** : After determining where the AR content should appear, the system generates and integrates the virtual imagery on the real-world view. Modern AR rendering techniques aim to produce photorealistic rendering of visuals that are indistinguishable from the real environment, taking into account lighting and shadows (Agusanto et al., 2003).

2.4.2 Display Technology

To superimpose the virtual overlay onto the real world, we employ dedicated display systems that merge both real and virtual components. Various categories of these systems can be identified:

[2] OpenCV Documentation : https://docs.opencv.org/4.x/d5/d1f/calib3d_solvePnP.html

Table 2.2 Types of AR Scene Recognition

Type	**Description**	**Pros**	**Cons**
Marker-based	Uses predefined markers or patterns to recognize and overlay virtual content.	Accurate, low computational requirements.	Requires predefined markers, less flexible.
Marker-less	Relies on natural features to identify locations for AR content.	More versatile, no markers needed.	Computationally intensive, needs strong features.
Object Recognition	Identifies known objects to anchor AR content.	Context-specific AR experiences.	Requires a database of objects.
Plane Detection	Identifies flat surfaces for placing virtual objects.	Natural placement on surfaces.	Limited to planes; complex objects challenging.
SLAM	Constructs/updates a map while tracking device's location.	Versatile, markerless.	Computationally intensive.

- **Head-mounted Displays (HMDs)**: Introduced by Sutherland (1968), these are the initial display types used for augmented reality systems. HMDs are equipped with a stereoscopic viewer and a device for head-motion tracking, typically affixed to a helmet (Edwards et al., 1993). They can be classified into two main types: (1) Optical See-through Displays: Taking after Sutherland's model, these allow users to perceive the real world, superimposing only the AR content through the use of transparent mirrors and lenses (see Figures 2.8a, 2.8b). (2) Video See-through Displays: In this setup, the system captures a live feed of the real environment, which then is overlaid with the AR graphics. The system blends the graphical content with live video footage and then presents this merge to the user (Van Krevelen and Poelman, 2010) (see Figure 2.8c).

- **Handheld (Mobile) Devices** : The evolution of mobile technology over the last decade, as pointed out by Arth et al. (2015), has transformed handheld computing devices into high-performance platforms capable of AR rendering. A spectrum of devices, ranging from UMPCs (Ultra Mobile PCs) to PDAs (Personal Digital Assistants), as well as tablets and cell-phones, have been employed as displays for augmented reality (Billinghurst et al., 2015). Modern smartphones and tablets, which are now ubiquitously adopted, come equipped with advanced graphics processors, cameras, location-based services (LBS), and a range of sensors optimized for AR applications.

Not only are these devices lightweight and compact, but they also support user locomotion. The visualization in AR is made possible through the device's built-in screen, with a camera integrated into the setup (see Figure 2.8d).

- **PC/Desktop**: Typically, this display aligns the real-world visuals captured by the computer's connected camera with a three-dimensional virtual model created by the computer itself, and then presents the merged view on the desktop screen (Chen et al., 2019).

- **AR Projectors**: This method projects the AR content directly onto real-world objects, leading to what is known as projective displays. These displays boast benefits like not necessitating special glasses, letting the user's eyes naturally focus, and providing a broad viewing area by covering expansive surfaces (Van Krevelen and Poelman, 2010). Typically less mobile (see Figure 2.8e), you could mostly find this kind of display in indoor settings like museums or art galleries, positioned at a stationary spot.

- **AR Contact Lenses**: These cutting-edge devices aim to integrate augmented reality technology directly within the slim structure of contact lenses. By achieving this, users can view digital graphics seamlessly blended with their usual field of vision. Research into AR contact lenses has been pursued by several (Berryman, 2012), with notable advancements from Mojo Vision, which initiated a prototype smart contact lens project in 2015 (Efron, 2023) depicted in Figure 2.8f. This prototype was tested and successfully utilized for the first time on June 23, 2022[3]. However, due to unfavorable economic conditions and the perceived premature state of the AR market, Mojo Vision discontinued the initiative in January 2023[4]. Current challenges for these devices include power sourcing, bio-compatibility, data transmission, and miniaturizing the necessary technology (Nourrit et al., 2021). Nonetheless, these lenses represent a potential future where AR becomes a near-invisible part of daily life.

Table 2.4 illustrates a comparative analysis of various display devices utilized to exhibit augmented reality visual content, evaluated based on several criteria including run-time, field of view, calibration necessity, visual fatigue, and hands-free usage. It's important to note that the specifications related to contact lens devices are not conclusive and predominantly derive from preliminary results of emergent research, such as the study conducted by Wu et al. (2018), where the 'Design of a near-eye display based on retinal projection with contact lenses' is presented.

[3] https://spectrum.ieee.org/looking-through-mojo-visions-newest-ar-contact-lens
[4] https://www.theverge.com/2023/1/7/23543224/mojo-vision-smart-contact-lens-microled

Table 2.3 Summary of Registration Methods in AR, based on the work of Yuan et al. (2005)

Type of Reg. Method	Description	Pros	Cons
Sensor-based	Utilizes dedicated sensors such as GPS, and magnetometers to determine the relationships between the viewer (or camera), the display, and the real world.	Fast performance	Might not be as accurate; potential for sensor drift and noise.
Computer-vision-based	The relationship between the camera, the display, and the actual surroundings is determined directly from sequences of images, without the necessity of additional sensors. This approach can either be classified as marker-based or reliant on natural features.	More accurate; robust when algorithms are well-designed.	Computationally intensive; might impact real-time performance.
Hybrid	Fuse data from multiple sensors or combine inertial and computer vision techniques, to overcome the weaknesses of certain methods.	Additional DOF; highly robust and accurate.	Latency; computationally intensive; require rigorous calibration.

(a) META 2 (b) VUZIX M100 (c) Oculus Rift + Zed Mini Camera (d) Google Pixel 3XL Smartphone

(e) Lightform "LF2+" AR Projector (f) Mojo Vision AR Contact Lens

Fig. 2.8 Examples of different types of augmented reality display devices.

Table 2.4 Comparative table of devices for displaying augmented reality visual content. the table has been adapted from the work of Havard (2018); Van Krevelen and Poelman (2010)

	Head-Mounted Devices (HMDs)			Handheld	Desktop	AR Projector		Contact Lenses
	Optical see-through	*Video see-through*	*Smart Glasses*	*Tablets and Smartphones*		*Mobile*	*Fixed*	
Hands free	YES	YES	YES	NO	YES	YES	YES	YES
FOV	23°-90°	110°	15°-30°	20°-50°	90°-100°	Human eye	Human eye	110°
Visual fatigue	YES	YES	YES	NO	NO	NO	NO	YES
Runtime	Limited	Limited	Limited	Limited	∞	Limited	∞	Limited
Interactions	Limited	Limited	Limited	Tactile	input peripheral	Limited	Limited	Limited
Outdoor use	YES	YES	YES	YES	NO	NO	NO	YES
Calibration required	YES	NO	NO	NO	NO	YES	YES	YES
Occlusion	YES	YES	Limited	Limited	NO	NO	NO	- -
Mobile	YES	YES	YES	YES	NO	YES	NO	YES
Sample devices	Figure 2.8a	Figure 2.8c	Figure 2.8b	Figure 2.8d	Computer and Camera	Figure 2.8e	standard projector and camera	Figure 2.8f

2.5 Key Patterns of AR in Tourism

In recent years, there has been a growing interest in immersive technologies in tourism research, leading to numerous published review studies. In this section, we present and discuss some of the most recent reviews, to identify trends and patterns in the literature.

Boboc et al. (Boboc et al., 2022) published a recent bibliometric review of 1201 articles over the past decade (2012–2021), which revealed eight trending topics of AR application to cultural heritage (CH), such as virtual museums, gamification, e-heritage, and user experience. Ideas on existing applications were described, based on discussing each trending topic.

Jingen Liang and Elliot (Jingen Liang and Elliot, 2021) provided a systematic review focusing on AR in the tourism literature. The results identified five emergent clusters, and established a robust statistical relationship between the perceived ease of use and the perceived usefulness for behavioral intention, which could provide reasonable evidence for future research alongside AR gamification.

Wei (Wei, 2019) presented a critical review of the progress of AR and VR research in tourism and hospitality, wherein they synthesized the stimuli, dimensions, and consequences of AR/VR related to user behavior, and highlighted fruitful directions for future research, such as the need for a cross-cultural approach, and predictive research on technological advances.

In a review conducted by Yung and Khoo-Lattimore in 2019 (Yung and Khoo-Lattimore, 2019), seven categories were identified within which the use of AR and VR in tourism has emerged, including marketing, experience enhancement, and tourism education. The review also identified gaps and challenges in the field, such as the usability and low awareness of AR and VR, and concluded that further theory-based research was needed to advance the field.

Loureiro et al. (Loureiro et al., 2020) reviewed current emerging topics, and avenues for future direction of AR and VR in tourism between 1995 and 2019, concluding that tourism experiences would be enhanced by adopting more brain–computer interfaces, wearable devices, and physical stimulation. The results also showed significant similarity among the emerging topics in the conference papers and journal articles.

Fan et al. (Fan et al., 2022) introduced an innovative meta-analytic framework that differs from previous review studies by examining the influence of the operating mechanism of AR/VR tourism applications on enhancing the tourist experience. This framework integrates both AR and VR technologies, and aims to identify the essential characteristics and theoretical operating mechanisms of immersive technologies in the context of tourism. The developed meta-analytical framework includes 24 constructs, derived from 65 independent studies in 56 articles, drawing upon the body of empirical literature mentioned in (Loureiro et al., 2020).

The analysis findings, involving 472 relationships, emphasize the pivotal role of "presence" as a key feature of AR/VR in the tourism domain. Additionally, the study reveals the positive moderating effects of "simulation type" and "social interaction" on the impact of presence on the tourism experience, while "prior visitation" demonstrates a negative moderating effect. Fan et al. justified the integration of the AR and VR analyses by stating that AR is a particular form of VR.

Zhou et al. (Zhou et al., 2022) conducted a recent review on the use of AR and VR in museum education. They performed a meta-analysis of 17 studies, to evaluate the impact of these technologies on learning outcomes.

Bekele et al. (Bekele et al., 2018) presented a comprehensive overview of the current status of AR, VR, and MR technologies in the CH domain, emphasizing the restrictions of present technologies, and the requirement for further research. The study also presented a framework for evaluating different systems, and determining the most appropriate solutions for a specific application.

In a broader context, Manuri and Sanna (Manuri and Sanna, 2016) conducted a survey that explored the primary application domains of AR, providing an overview of current technologies and future trends. Their study identified various domains, including tourism and cultural heritage, as well as education, medicine, the military, and entertainment. The authors concluded that the progress of AR technologies is closely linked to advancements in AR devices, and the availability of content, which will be further discussed in the systematic review section of our study.

The key patterns identified across various AR studies encompass virtual museums, gamification, user experience, behavioral intention, cross-cultural research, experience enhancement, brain-computer interfaces, wearable technologies, presence in AR/VR applications, tourism education, and advancements in AR device technologies.

It was noted that there is a growing trend in the literature for reviews that cover both AR and VR technologies. However, it is important to distinguish between these technologies, as they have unique characteristics and purposes (see Section 2.2.3). AR enhances the user's perception of the real world, by overlaying virtual information, while VR creates a fully immersive and artificial environment for the user experience. As reported by Yung and Khoo-Lattimore in (Yung and Khoo-Lattimore, 2019), the cluster of studies related to enhancing the tourism experience using emerging VR and AR technologies in tourism was found to be exclusively composed of AR studies. This highlights the need for further research into the specific application of AR in tourism.

The above-mentioned studies also indicate that the use of a combination of qualitative and quantitative methods of analysis in literature reviews is uncommon. Bibliometric analysis

provides a quantitative perspective on the literature, including identifying trends and highly cited works (Boboc et al., 2022; Dey et al., 2022; Knani et al., 2022), while content analysis offers a qualitative perspective, including research methodologies, gaps, and implications (Wei, 2019; Zhou et al., 2022). A more holistic and nuanced understanding of AR research within the field of tourism could be achieved by incorporating both bibliometric and content analyses.

2.6 Personalized Augmented Reality (PAR)

2.6.1 The Notion of Personalization

Based on the perspective of "interactive Marketing", Montgomery and Smith (2009) define personalization as adapting marketing elements to an individual level. They offer a broader definition, stating that personalization is "*the adaptation of products and services by the producer for the consumer using information that has been inferred from the consumer's behavior or transactions*".

According to Salonen and Karjaluoto (2016), in the web domain, personalization is generally characterized by dynamic adaptation to individual consumer preferences through automated processes. This adaptation process encompasses areas such as sophisticated recommendation systems and in-depth user profiling.

The terms "personalization" and "customization" are often used interchangeably, leading to some confusion in their meaning. In general, to emphasize the difference between the two concepts, researchers consider personalization to be a company-driven (implicit), automated process, while customization is seen as a user-initiated process (explicit) (Salonen and Karjaluoto, 2016).

Tam and Ho (2006) categorized personalization into three distinct types:

- *User-driven Personalization*: Users explicitly specify the layout and content of the website according to their interests and preferences, often referred to as "customization".
- *Transaction-driven Personalization*: Personalized layout and content are automatically generated by online merchants, utilizing previous transactions.
- *Context-driven Personalization*: An adaptive mechanism that employs advanced techniques to understand user context and infer their real-time behavior.

The personalization of virtual interfaces can be approached in two distinct ways, according to the data collection methods, as Liarokapis et al. (2008) point out:

- *Explicit (static) personalization*: In this case, users provide their personal data and preferences explicitly, through media such as questionnaires or ratings. This includes data such as age, interests, level of education, and specific needs. Although this method delivers high-quality, customized personalization, it can be time-consuming for users.

- *Implicit (dynamic) personalization*: This approach relies on the user's behavior and interactions with the system to deduce preferences. Techniques used include monitoring time spent on pages, tracking visited links, collaborative filtering, and analyzing cookies. It offers a seamless experience for the user, as it works in the background without requiring direct input. However, its accuracy does not always perfectly match the user's actual preferences.

In Chapter 4 of this thesis, we introduce a personalized mobile augmented reality model that integrates both static and dynamic personalization methods. While the static approach utilizes the user's profile for personalization, the dynamic approach analyzes the user's interaction time with Points Of Interest (POIs).

2.6.2 Personalized AR Systems in Tourism

Personalized AR systems offer a promising route to adapting augmented content, recommendations, and interactions to the specific interests and needs of tourists. This section discusses the shift in researchers' focus from generic to personalized AR interfaces. We'll also look at how researchers modeled these personalized systems and what concepts were used.

In the past few years, a proliferation of projects and prototypes has highlighted the potential of AR in enhancing tourism experiences, across both indoor and outdoor settings. Specific indoor-oriented systems, such as MRsive (Al Rabbaa et al., 2019), M5SAR (Rodrigues et al., 2019), and Ear-AR (Yang et al., 2020), as well as outdoor-targeted applications such as GokovAR (Demir and Karaarslan, 2018), MAJD (Al-Mutairi et al., 2019), and LecceAR (Banterle et al., 2015), have been introduced to the field. Though, these systems often adopt a standardized approach of one-size-fits-all content delivery, presenting the same information to all users, which fails to address individual needs and interests.

Nonetheless, researchers are increasingly directing their focus towards personalized AR experiences. Several pioneering projects have made their way into the literature, proposing the design of customized AR systems that adapt to the user's context and preferences.

Zhu et al. proposed in (Zhu et al., 2004) a conceptual framework for a context-aware shopping assistant that utilizes AR to deliver personalized advertising and shopping support based on dynamic contextualization using location, product, and user contexts. The design methodology described in their work holds potential for extension to the domain of tourism

guides. ARCHEOGUIDE (Vlahakis et al., 2002) is a mobile-wearable system developed by Vlahakis et al., specifically designed to provide personalized AR tours in archaeological sites by adapting to users' profiles. The system employed a hybrid technique that combined user preferences and positioning data to deliver tailored information. The study demonstrated positive user acceptance of the system, irrespective of whether the user was an expert or an ordinary visitor. Rezaee et al. developed in (Rezaee et al., 2021) a location-based mobile AR tour guide that offers personalized experiences by predicting user interests based on their profile and extracting relevant data from big data sources. The study employed VIKOR and SWARA methods to consider spatiotemporal contexts. User evaluation results indicated a high level of satisfaction among participants, particularly in terms of system usability.

In the domain of recommendation systems for tourism, Aksenov et al. introduced in (Aksenov et al., 2016) a concept for a recommender system tailored to urban tourism and historical sightseeing. Their system provides personalized tour recommendations by considering user profiles, specific cultural preferences, and preferred transportation modes. By leveraging these factors, the system aims to enhance the tourist AR experience and enable visitors to explore relevant attractions in a customized manner. In a related context, Kalloori et al. (Kalloori et al., 2023) presented a mobile AR prototype that generates context-aware recommendations for POIs based on user profiles and interests. The system utilizes a model that captures user preferences through an active learning strategy, taking into account the user's personality traits. By leveraging this approach, the prototype offers personalized recommendations that align with the user's preferences and interests, enhancing the relevance and quality of the suggested POIs.

Other projects have explored the integration of social media content to offer personalized AR experiences and generate recommendations for POIs. Balduini et al. (Balduini et al., 2012) employed inductive and deductive stream reasoning techniques to extract insights from Twitter community opinions regarding specific restaurants. By mining this social media data, the project generated personalized recommendations for restaurants based on the collective opinions and sentiments shared by users. On the other hand, Torres-Ruiz et al. (Torres-Ruiz et al., 2020) combined data mining techniques to analyze user ratings and opinions sourced from social media, along with data from Internet of Things (IoT) sensors. The project aimed to generate and recommend itineraries for indoor and outdoor museum visits. By leveraging the wealth of information available from both social media and IoT sensors, the system was able to offer tailored itineraries that considered user preferences and interests.

In the context of Audio AR (AAR), Kaghat et al. introduced SARIM an adaptive gesture-based audio AR system specifically designed for museum visits in (Kaghat et al., 2020). SARIM incorporates content personalization by combining head gestures and continuous

update of user interest prediction to enhance the AR experience. The evaluation of the system demonstrated the ease of use, usefulness, and the enjoyment it brings to users during their museum exploration.

2.7 Augmented Reality Evaluation

In this section, we will be interested in how researchers have transitioned from technology-centered evaluation to user-centered evaluation. In a second step, we will narrow the scope of AR applications to only include those in the context of tourism, and we will demonstrate how AR applications in the tourism context are evaluated. Lastly, we will outline the various types of AR evaluation and the applicable evaluation methods.

2.7.1 Focus on User-Centric Evaluation in Augmented Reality

Even though the first early prototypes were presented almost fifty years ago (Sutherland, 1968), the academic community only started to get interested in augmented reality research in the 1990s (Dünser and Billinghurst, 2011). More recently, AR technology is being used in a wide range of industries (Marketing, Medicine, Education, Entertainment, Tourism, etc.)(Billinghurst et al., 2015). Thus, the challenge here is to create usable AR systems. Developments should focus on user needs rather than technology to present solutions and determine which users will use the application (Carmigniani et al., 2011).

Swan and Gabbard (Swan and Gabbard, 2005), persuaded of the significance of user-centered evaluation, published a survey in this context. They examined a total of 1104 articles from prestigious conferences and journals (ISMAR, ISWC, IEEE virtual reality, presence), and discovered that only 21 (or 2% of all papers) explain formal user-based experiments, whereas 266 publications (or about 24%) are concerned with AR research. The authors acknowledge the necessity for continued development of AR systems by shifting from technology-centric to user-centric medium in light of these findings.

Three years later, A similar survey about the evaluation methods applied in AR research between 1993 and 2007 was created by Dünser et al.(Dünser et al., 2008) to extend previous work. As a result, 161 out of 3309 articles were AR user evaluation publications (28.9% of the total after KW selection & 10.4% of total AR after KW selection), but only 120 described formal AR user evaluation (21.5% of the total after keyword selection & 7.8% of AR papers after keyword selection).

A review of the ten-year evolution of the work presented at the ISMAR leading and inaugural AR meeting was also published in 2008 by Zhou et al. (Feng Zhou et al., 2008).

They divided the previous AR research from 313 papers into eleven categories, one of which was "Evaluation". Only 1.8% of the most referenced papers were evaluated/tested AR systems, and only 5.8% of papers (18 out of 313) were devoted to this topic.

Findings indicate that until 2008 there wasn't enough engagement from the AR research community in the area of AR interfaces evaluation and user-based experiment although the statistics confirm the increasing comprehension of the importance of augmented reality evaluation.

In 2018, Kim et al. (Kim et al., 2018) published a review of the 2nd decade of ISMAR in the same context as Zhou et al.'s summative survey (Feng Zhou et al., 2008). The authors added four new categories to the original list: perception, collaboration, reconstruction, and modeling. According to the average cites per year, one of the most cited five research topics was "Evaluation" revealing a sharp increase in AR evaluation research, they found that 16.4% of total papers related to AR evaluation. Kim et al. interpreted this significant increase as the fact that when a new application or method is introduced into ISMAR, the papers have to include some form of evaluation, which was not always the case in the first decade of the conference.

2.7.2 Assessing Augmented Reality in Tourism Settings

When we analyze the state of the art related to augmented reality research, we would find limited studies that implemented and discussed user-based or expert-based experiments of visual augmented reality in the field of tourism and guiding users through outdoor navigation systems. On the other hand, there is a growing intention to design more innovative applications to improve tourist experiences and promote the cultural heritage of historic cities (e.g. (Zaifri et al., 2018)).

Chen (Chen, 2014) presents in his paper the design, implementation, and evaluation of a mobile AR application that displays historical images of a historical sight. The author conducted two usability evaluations: a heuristic evaluation using Nielsen's ten heuristics (Nielsen, 2005) and a hallway test which was carried out using the Think Aloud Protocol. The results showed a generally positive attitude among users.

Kourouthanassis et al. (Kourouthanassis et al., 2015) published an interesting paper in which they reported the development process of a mobile AR travel guide that supported personalized recommendations named CorfuAR. In addition, they explored the adoption of MAR applications and their impact on users' emotions through fieldwork with the help of 105 participants who filled out the evaluation questionnaire. Results of the study show that CorfuAR interaction functionalities evoke feelings of pleasure and excitement, which influences in return the behavioral intention of using the application.

Schaeffer (Schaeffer, 2014) took the task of adapting and applying usability evaluation techniques to evaluate four different applications of augmented reality, one of them being the Wikitude navigational application. The work edited by Schaeffer describes two evaluation methods: a modified heuristic evaluation where they adapted Nielsen's ten heuristics (Nielsen, 2005) to fit AR evaluation, and real environment usability testing by observing and taking notes (objective measurements (Dünser et al., 2008)). Many usability issues were revealed such as the overall instability and limited number of POIs.

Phithak et al. (Phithak and Kamollimsakul, 2020) developed a mobile AR application called "Korat Historical Explorer" intended to promote historical tourism in Korat province in Thailand, which has more than 2000 temples. After the app was designed and developed, it was submitted to 9 experts for usability evaluation based on five aspects: efficiency, effectiveness, flexibility, learnability, and user satisfaction. Then, the authors recruited 35 users to use and evaluate the application based on the same parameters as the experts. We believe that the evaluation of AR in the context of tourism should include more aspects than just usability, such as navigation and enjoyment, and we believe that the feedback from experts and novice users might be interpreted differently; therefore, the two evaluations should be performed separately.

Han et al. (Han et al., 2021) published a study on the impact of AR experiential value in the context of heritage tourism. The authors found that the multidimensional components of AR experiential value (i.e., visual appeal, entertainment, enjoyment) have a significant positive effect on destination authenticity and AR satisfaction. The study sample consisted of 355 participants who were recruited through a random sampling approach from Amazon Mechanical Turk. While online surveys can collect valuable user data, we believe that field experimentation is a more effective method of collecting pertinent data on user performance.

2.7.3 Methodologies and Approaches for Augmented Reality Evaluation

User-based evaluation types for AR.

According to Swan and Gabbard (Swan and Gabbard, 2005), user-based experimentation in AR can be categorized along three axes:

- Human perception and cognition
- User task performance and interaction techniques
- User interaction and collaboration

Dünser et al. discovered in (Dünser et al., 2008) a fourth category during their classification that they named:

- Interface or system usability studies.

Usability inspection is the generic name for a set of cost-effective ways of evaluating user interfaces to find usability problems (Nielsen, 1994b). Usability tests allow AR researchers to evaluate AR user interfaces and gather experts' feedback for technical improvements. There are currently no general guidelines or heuristics for visual augmented reality (Dünser and Billinghurst, 2011). However, as AR system designers, we should be able to rely on general HCI principles identified so far (Dünser et al., 2007).

User-based evaluation methodologies for AR.

Dünser et al. (Dünser et al., 2008) also propose another classification for user evaluation methods and approaches as follows:

- Objective measurements (error rates, task completion time, number of actions).
- Subjective measurements (questionnaires, user judgments).
- Qualitative analysis (formal user observations or interviews).
- Usability evaluation techniques (heuristic evaluation, TAP method, expert-based evaluation).
- Informal evaluations (informal collection of user feedback).

2.8 Research Gap Analysis

Table 2.5 outlines three research gaps: conceptual, empirical, and geographical. Each gap highlights a distinct field in which the existing literature may be insufficient or remains under-explored. Within this thesis, we not only identify these gaps but also address them, thus enriching the academic discourse in our field.

In this section, we offer a detailed exploration of each identified gap, shedding light on our unique contributions to the literature.

Conceptual gap

Following the literature discussed in Section 2.6, many personalization frameworks primarily utilize static methods, leveraging demographics and preferences. Some also incorporate social media-based recommendations. Notably, these systems often model user interests only once, recommending specific POI types. This thesis challenges the conventional methodologies

Table 2.5 Research gaps addressed in this thesis

Research Gap	Description	How the Gap was addressed	Relation to the thesis
Conceptual	Most AR solutions for tourism are generic and not personalized.	Addressed by introducing FEZAR prototype in Chapter 4.	Introduce FEZAR, a personalized, mobile AR prototype specifically designed for the tourist experience.
Empirical	Need for data on AR's impact on tourist experience in crowded destinations. Limited studies exploring the impact of AR on various aspects of the tourist experience.	Addressed by conducting empirical experimentation in Chapter 5.	Conduct a comparative field study of FEZAR against conventional tourism guidance tools, exploring the impact of mobile AR on navigation, enjoyment, and information accessibility in crowded tourist areas.
Geographical	AR research in tourism is concentrated mainly in Europe and Asia and very limited in North Africa.	Addressed by conducting empirical experimentation in Chapter 5.	Conduct the experimentation in Fez, Morocco, North Africa, diversifying the geographical scope of AR in tourism research.

by introducing a holistic approach, merging both static and dynamic personalization. It not only accounts for pre-visit user profiles but also real-time interactions, allowing continuous interest updates and adaptable POI recommendations. This proposed method addresses users' evolving interests throughout their visit. To bridge the identified conceptual gap, we present FEZAR, a conceptual model for personalized mobile AR tour guide systems.

Empirical gap

AR applications offer a distinct layer of interaction with the real world, differentiating them from regular applications. Usability testing of such systems is imperative to ensure their effectiveness and ease of use. In the tourism sector in particular, we advocate evaluating augmented reality applications in authentic environments, such as crowded historical destinations, to gain the best possible understanding of the user experience (UX).

From the discussions in Section 2.7.2, the literature review highlights a significant empirical gap concerning the evaluation of AR applications for tourism. While numerous

studies prioritize usability assessments or user acceptance of the technology, they often overlook crucial UX elements beyond usability. These include aspects like informativeness, enjoyment, and navigation.

This thesis aims to bridge this empirical gap by conducting an empirical comparative field study, emphasizing four core UX dimensions: usability, navigation, informativeness, and enjoyment. Consequently, this research aims to explore the impact of a mobile location-based AR in providing support to tourists navigating through crowded urban areas.

Geographical gap

Table 2.6 illustrates the geographical distribution of AR studies in the tourism sector, based on our examination of the most recent systematic and bibliometric reviews, as discussed in Section 2.5.

Table 2.6 clearly demonstrates that the majority of studies on AR in tourism have their affiliations in Europe and Asia, with America and Australia following. Europe's significant output comes mainly from countries like the UK and Italy, while in Asia; most studies come from countries like China, Malaysia, Taiwan, and South Korea. On the other hand, contributions from North America come mainly from the USA. Africa seems notably underrepresented in this field of research, with only one isolated contribution from South Africa.

The scarce research activity in African regions compared to Europe and Asia highlights a potential geographical gap in research. As part of this thesis, we attempt to narrow the geographical gap by carrying out an empirical study in the Medina of Fez, thus contributing to the literature from the North African perspective.

2.9 Conclusion

In this chapter, we have started by exploring the historical development and dynamic definition of AR. We positioned it on a continuum from real to virtual environments, contrasting it with VR. To clarify for subsequent chapters, we defined the concept of MAR. This concept has evolved from the idea of mobilized AR to its implementation on mobile devices, such as smartphones. We have focused in particular on visual augmentation, breaking down this process from scene recognition to the display of virtual information through various visualization devices, including HMDs, handheld devices, projectors, and desktop computers. Narrowing the discussion to the field of tourism, we identified key patterns and trends in the application of AR in tourism, through a review of recent systematic and bibliometric literature reviews as of 2016. Key concepts included virtual museums, gamification, UX, behavioral intent, experience enhancement, brain-computer interfaces, and wearable technologies. Next,

Table 2.6 Distribution of reviewed studies by cultural context (by continent).

Author(s)	Europe	Asia	North America	Australia	Africa
Wei (2019)	25	13	12	1	0
Zhou et al. (2022)	22	7	11	0	0
Kuhail et al. (2022)	15	10	16	1	1
Jingen Liang and Elliot (2021)	25	6	3	1	0
Boboc et al. (2022)	732	77	0	32	0
Loureiro et al. (2020)	✓	✓	-	-	-
Loureiro and Nascimento (2021)	✓	✓	✓	✓	-

✓: Author(s) identified the cultural context through qualitative assessment or bibliometric analysis without specific numbers for each continent.

we have limited our field of study to personalized AR systems in the specific case of visits to cultural sites. Our analysis revealed that a limited number of systems prioritize capturing visitors' behaviors during their tour to customize the experience accordingly. In the final part of our state-of-the-art study, we identified and categorized the different types and methods used to evaluate AR interfaces, which are significantly distinguished from conventional interfaces. We also showed how AR evaluation has shifted from technology-centric to user-centric. In the field of tourism, we demonstrated how different AR systems are being evaluated to assess and improve the visitor experience. Finally, we highlighted and analyzed three distinct research gaps identified throughout this chapter: conceptual, empirical, and geographical. Table 2.5 describes each gap and its relevance to our thesis.

Chapter 3

Bibliometric and Systematic Analysis of Augmented Reality Applications in Tourism Sector

3.1 Introduction

Augmented reality (AR) technology, a variant of virtual environments (VE) that allows users to see the real world with virtual objects overlaid in real-time (Azuma et al., 2001), has emerged as a tool that can revolutionize tourism, offering enhanced and immersive experiences. Researchers and tourism practitioners have recognized AR's potential in tourism since 2000 (Jingen Liang and Elliot, 2021). Given the growing interest in AR applications in tourism and the considerable promise that AR holds for this sector (as discussed in Section 1.1.3), it's imperative to understand the progression, different contexts, and design components of AR technology in tourism.

This chapter aims to provide a comprehensive overview of AR research in tourism, by doing so, we intend to inform researchers, industry practitioners, policymakers, and educators about the current state of the field and potential research directions. Ultimately, this knowledge can contribute to the advancement of AR technology in tourism, improving the overall tourist experience, and relaunching tourism post-COVID-19.

This chapter details a review spanning twenty-one years (2002–2022), employing a dual-methodology to screen and examine pertinent research articles. Firstly, a bibliometric analysis was conducted on 861 articles to (1) highlight emerging topics and contexts of AR use in tourism, and (2) explore the evolution of research production over time and across countries. Secondly, we carried out a systematic content analysis on the 57 selected studies,

to (3) summarize the most commonly used AR design elements in tourism settings. Finally, this chapter offers insights into research gaps and potential future directions.

This chapter is organized in the following manner: Section 3.2 details the methodology utilized to review relevant papers. Section 3.3 presents and interprets the results, covering emerging themes and applications of AR in tourism, the distribution of research production temporally and geographically, as well as frequent AR design features in tourism settings. Section 3.4 proposes avenues for future AR research within the tourism industry. Lastly, Section 3.5 discusses the limitations of our study and offers insights into potential enhancements for future research.

3.2 Methodology

The bibliometric approach employs quantitative methods on bibliographic data, enabling researchers to uncover the dynamic nuances and identify emerging trends within a particular field (Donthu et al., 2021). In this chapter, Zaifri et al. (2023a)'s bibliometric analysis aimed to pinpoint the principal areas and contexts in the tourism sector impacted by AR. Zaifri et al. (2023a) also explored the chronological development and geographic spread of AR research in tourism through this analytical method (Zaifri et al., 2023a).

Systematic content analysis is a frequently used research technique characterized by the subjective examination of text through a methodical process of categorization. This process involves coding and identifying themes within the data (Hsieh and Shannon, 2005). In this chapter, Zaifri et al. (2023a) utilized content analysis to discern and encapsulate the design features of AR technology specific to tourism applications. Subsequently, they delve into prospective developments for AR in the tourism industry, drawing on the insights gained from our current study.

3.2.1 Literature Search and Data Gathering

Zaifri et al. (2023a) obtained relevant literature on AR in tourism from Scopus and Web of Science (WoS) databases. The search, conducted on January 23, 2023, targeted text, abstracts, and keywords using the query: *((“augmented reality”) AND (“touris*”))*. This query was restricted to publications from January 1, 2002, to December 31, 2022.

Scopus and Web of Science (WoS) are recognized as the foremost multidisciplinary databases for sourcing a comprehensive collection of pertinent and high-quality articles. This approach is validated by previous studies and systematic reviews, confirming the robustness of these platforms (Jingen Liang and Elliot, 2021; Loureiro et al., 2020; Yung and Khoo-

Lattimore, 2019; Zhou et al., 2022). To refine the search on both Scopus and WoS, Zaifri et al. (2023a) applied several filters: the document type was limited to articles and conference papers, and only final versions published in peer-reviewed journals or conference proceedings, and available in English, were selected for analysis.

The initial search across the Scopus and Web of Science databases yielded a total of 1206 articles, with 615 from Scopus and 591 from WoS. Zaifri et al. (2023a) then transferred these records to the "Zotero" literature management tool for the purpose of removing duplicates and further selection for systematic content analysis. The merging of the datasets in Zotero resulted in the identification and removal of 345 duplicate entries, culminating in a refined set of 861 articles. Subsequently, these 861 articles were imported into the Bibliometrix R tool, "*Biblioshiny*", for a detailed bibliometric analysis.

3.2.2 Process of Screening and Selecting Literature

Zaifri et al. (2023a) employed the PRISMA 2020 framework (Page et al., 2021) for a structured approach to literature identification and screening, as depicted in Figure 3.1. Post-duplicate removal, 861 records remained for further examination based on criteria listed in Table 3.1. The initial screening of titles and abstracts led to the exclusion of 583 records that did not align with the inclusion criteria, except for the second criterion. This left 278 records, from which the full texts of 118 reports were retrievable for detailed analysis. Technical challenges like restricted access obstructed the access to the remaining 160 records, despite utilizing both manual (online search) and automated (Zotero) methods.

In the subsequent stage, an in-depth examination of the full texts was conducted against the inclusion and exclusion criteria, identifying content not evident in the abstracts. This led to the elimination of 61 studies for various reasons: 15 did not detail AR system implementation, 1 merged AR and VR technologies, 5 had incomplete article sections, 18 focused solely on theoretical AR research in tourism, and 22 lacked practical evidence of AR application in tourism. Efforts to expand the list of reports through citation searches yielded no additional relevant articles. Consequently, 57 articles were finalized for the content analysis. Throughout the selection process, two researchers independently reviewed all articles, resolving any discrepancies through discussion until consensus was reached.

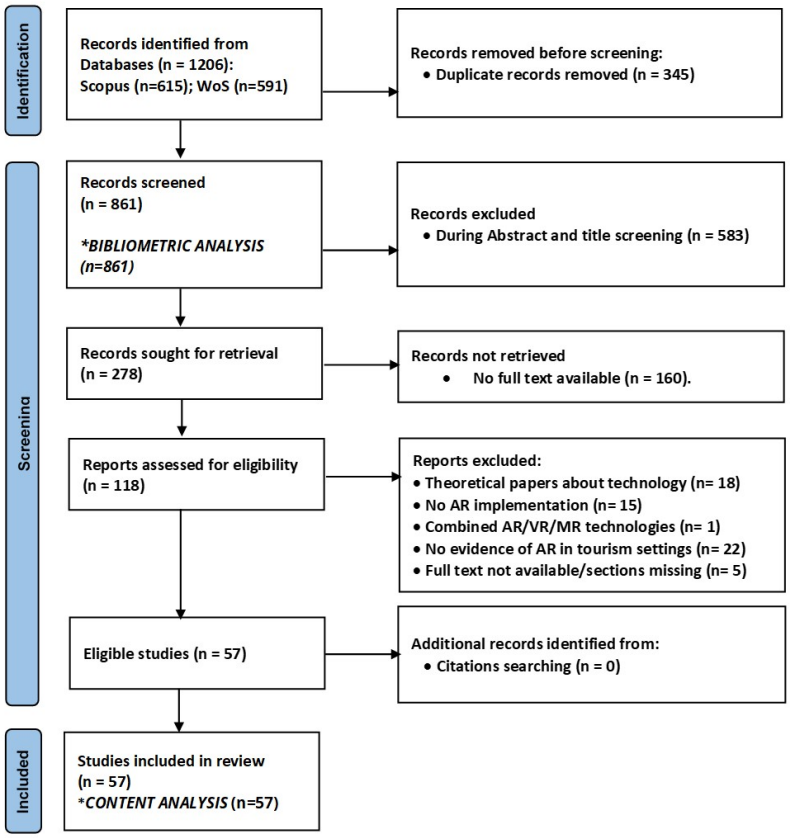


Fig. 3.1 Methodology for Final Paper Selection Following the PRISMA 2020 Guidelines

3.2.3 Data Analysis

Analysis via Bibliometrics

In this chapter, Zaifri et al. (Zaifri et al., 2023a) utilized two fundamental bibliometric methodologies: performance analysis and science mapping. Performance analysis employs specific metrics to evaluate contributions in research, such as those by authors or from different countries. Here, Total Publications (TP) and Total Citations (TC) served as key metrics, shedding light on the productivity and influence of various countries in AR research in tourism.

Science mapping, in contrast, focuses on uncovering relationships among various research elements. In this study, co-word analysis, specifically word co-occurrence, was employed to pinpoint primary areas where AR is applied in tourism and to illustrate the conceptual framework of evolving topics in this field. More precisely, a keyword co-occurrence analysis

Table 3.1 Inclusion and Exclusion Criteria for Data Selection (Zaifri et al., 2023a)

Criteria	Inclusion	Exclusion
Language	English	Not English
Access	Full text	Full text not available, missing sections, preprints.
Type of article	Journal article, conference paper, book chapter	Poster, editorial
Research methodology	Empirical study	Theoretical study, review, extended abstract
Evidence of AR in tourism	Reported	Not reported
Addressing RQ3	Yes	No
Field of study	Pure AR	Combined AR/VR/MR

was performed using the authors' keywords to identify dominant themes emerging from the body of literature on AR in the context of tourism.

For the analysis and visualization of bibliographic data in their review, Zaifri et al. (Zaifri et al., 2023a) used *Bibliometrix*[1], an open-source software that leverages R programming for scientific mapping analysis. This software facilitated the creation of data networks and visualizations. The application of *Bibliometrix* is a well-established and popular approach for scientific mapping, recognized for its flexibility and efficiency in network generation, as noted by Aria and Cuccurullo (Aria and Cuccurullo, 2017).

Framework for Analysis and Coding of Content

In addressing Research Question 3 (RQ3), Zaifri et al. (Zaifri et al., 2023a) implemented content analysis through a directed approach, as suggested by Hsieh and Shannon (Hsieh and Shannon, 2005). They established an initial coding framework derived from previous reviews to categorize and synthesize the insights from the 57 selected articles. This framework covered various aspects, such as AR tracking systems, devices used for AR technology, types of virtual content, and the tourism contexts in which AR is applied. This method of analysis facilitated the emergence of sub-themes and the definition of their distinct characteristics.

- **AR system categorization:** Adopting the classification framework from Kuhail et al. (Kuhail et al., 2022), Zaifri et al. (Zaifri et al., 2023a) segmented AR systems into three primary categories with five subcategories, as detailed in Table 3.2

[1] Bibliometrix: https://www.bibliometrix.org/home/index.php/layout/bibliometrix

- **Classification of tourism environments:** Following Bekele et al.'s methodology (Bekele et al., 2018), Zaifri et al. (Zaifri et al., 2023a) organized tourism environments into four distinct categories, showcased in Table 3.3.
- **AR device codes:** The coding for AR technology devices, presented in Table 3.4, is based on the frameworks by Bekele et al. (Bekele et al., 2018) and Zhou et al. (Zhou et al., 2022), as adapted by Zaifri et al. (2023a).
- **Virtual content categories:** Zaifri et al. (Zaifri et al., 2023a) classified the virtual content in AR technologies into six types based on sensory stimulation, as enumerated in Table 3.5.

In the early phase of formulating the coding frameworks, Zaifri et al. (Zaifri et al., 2023a) engaged in team discussions, incorporating insights and obtaining approval from co-authors. Whenever disagreements arose, they conducted additional discussions to reach a mutual consensus.

3.3 Results and Discussion

Zaifri et al. (Zaifri et al., 2023a) noted that, from 2002 to 2022, a total of 861 primary research articles focusing on AR's application in tourism were identified in the Scopus and WoS databases. These articles showed a yearly growth rate of 25.77%, reflecting an increasing interest in this domain over the two decades. The collection of these articles came from 610 different sources, incorporating 1944 Plus keywords and 2105 author-specific keywords. A total of 2463 authors contributed to these publications, with 79 being single-authored and the rest averaging 3 to 4 authors per paper. The international collaboration rate among these authors was 13.43%, highlighting significant global research collaboration in the field of AR in tourism.

3.3.1 Annual and Geographical Trends in Research Output

Zaifri et al. (Zaifri et al., 2023a) analyzed the evolution of AR research in tourism by examining the annual distribution of published papers. The progression in the number of research papers issued each year is depicted in Figure 3.2. This timeline illustrates three separate phases of research activity, each marked by unique contributing factors.

The initial phase, from 2002 to 2008, represents the early development of AR research in tourism, characterized by a modest output of 1 to 5 publications annually. Zaifri et al. (Zaifri et al., 2023a) attribute this limited productivity to the emerging nature of AR technology,

Table 3.2 Framework for Coding AR Tracking Systems by Zaifri et al. (2023a)

Category	Sub-category	Explanation
Marker-based	Image	AR technology uses predefined images (e.g. QR codes) to track and overlay virtual content.
	Object	AR technology uses predefined physical 3D objects (e.g. chair, table) to track and overlay virtual content.
Marker-less	Location-based	AR technology takes a physical location in a form of GPS coordinates and delivers customized digital content based on that location.
	Projection-based	Video projection technology is used in combination with AR technology to enhance physical environments by overlaying virtual images onto physical surfaces. (e.g. a virtual keyboard displayed on a table that enables users to input data)
	Superimposition-based	AR technology overlays digital content directly onto real world objects in real-time (e.g. track person's face features and add virtual glasses)
Hybrid	–	Hybrid systems utilize a combination of technologies from both marker-based and marker-less systems, including projects that utilize different technologies within the same system.

Table 3.3 Framework for Coding Tourism Contexts as Developed by Zaifri et al. (2023a)

Category	Explanation
Indoor	Refers to AR experiences in closed environments (e.g., museums, exhibitions, shopping centers).
Outdoor	Refers to AR experiences in open environments (e.g., natural parks, cities, cultural landmarks).
Combined	Refers to AR experiences in both open and closed environments.
Not specified	The location of the AR experience is not specified, either because it is not relevant to the study, or because it is not mentioned.

the dearth of practical applications at the time, and a general lack of recognition of AR's potential in tourism. This era is marked by the foundational work of researchers exploring the capabilities and applications of AR in the tourism sector.

Table 3.4 Framework for Coding AR Technology Devices by Zaifri et al. (2023a)

Category	Explanation
Handheld	AR technology is deployed on mobile and wireless computing devices (e.g., smartphones, tablets).
Head-Mounted-Display (HMD)	AR technology is deployed with head-worn devices or built-in helmets that contain a small computer and monitor (e.g., AR Smart Glasses, AR headsets).
Desktop	AR technology is deployed using stationary desktop computers and digital devices that cannot be easily relocated (e.g., AR training simulator).
Spatial	Augmentation is achieved using video projectors and tracking devices, to project digital content directly on the physical surface.
Not specified	AR device was not specified in the study.

Table 3.5 Coding Structure for Virtual Content by Zaifri et al. (2023a)

Category	Explanation
Visual	Images, graphics, and videos are used to enhance the visual experience, such as 2D objects or 3D models.
Auditory	The sound is used to enhance the AR experience (e.g., background music, sound effects, voice recordings).
Haptic	Touch sensations are used to add a sense of physical interaction to the AR experience (e.g., vibration, force feedback).
Olfactory	Scents are used to enhance the AR experience. This type of virtual content can be used by adding familiar scents to the environment.
Gustatory	Gustatory virtual content uses taste to enhance the AR experience. This type of content can be used to simulate the taste of food or drinks through haptic technology or other means.
Multi-sensory	Multi-sensory virtual content combines multiple senses, including visual, haptic, auditory, olfactory, and gustatory, to create a fully immersive AR experience.

The second phase, from 2009 to 2019, as identified by Zaifri et al. (2023a), shows a significant upsurge in research production, with annual publications varying from 8 to 131. This increase reflects the evolution and increased accessibility of AR technology, along with a growing awareness of its applicability in tourism. During this time, the scope of research

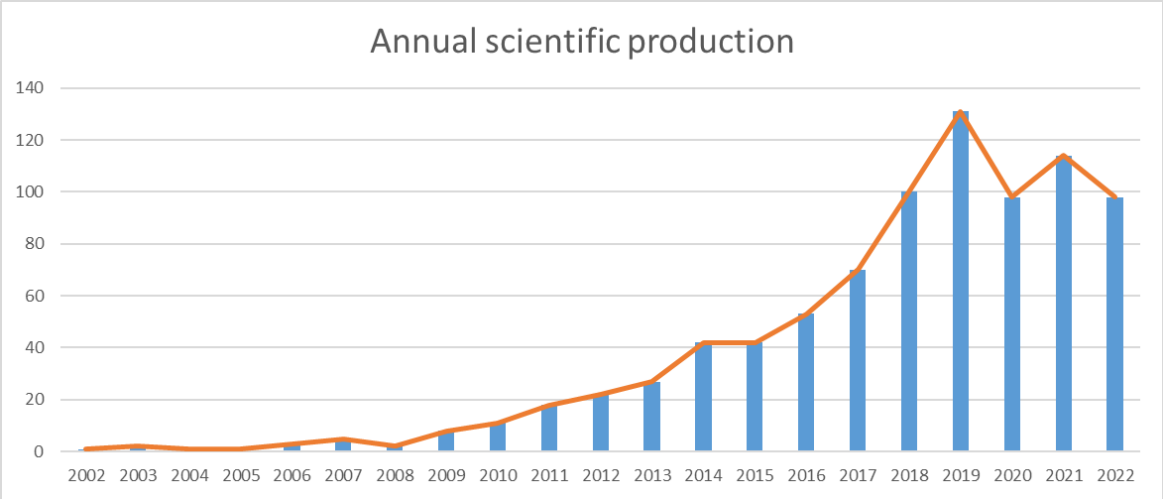


Fig. 3.2 Yearly Research Output in AR Tourism (2002-2022) by Zaifri et al. (2023a)

broadened to encompass diverse themes including design, development, gamification, user experience, satisfaction, and behavioral intentions, indicating a growing breadth of interest in the area (refer to Section 3.3.2).

In the third phase, spanning from 2020 to 2022, Zaifri et al. (Zaifri et al., 2023a) observed a stabilization in the volume of research publications, with an average of around 98 articles per year in both 2020 and 2022. This period, known as the post-COVID-19 era, began in full in 2021, following a temporary dip in research output in 2020 due to the pandemic's impact. This recent phase is marked by a resurgence in interest in AR tourism research. The tourism industry, in response to the pandemic, increasingly turned to innovative technologies like artificial intelligence and machine learning to address new challenges and shifts in consumer behavior brought on by the pandemic.

Figure 3.3 illustrates the global distribution of regional scientific output in AR tourism research. Zaifri et al. (Zaifri et al., 2023a) highlight Italy's leading role in this domain, contributing 170 publications, accounting for 20% of the total. China follows with 142 publications (17%), and the UK with 87 (10%). The comparative analysis of these countries' contributions reveals the diverse regional and economic contexts influencing the field's development and diversity.

Figure 3.4 depicts Europe's robust engagement in AR tourism research, as evidenced by substantial contributions from Italy, the UK, Greece, Portugal, and Spain. Simultaneously, Asian countries, including China, Malaysia, South Korea, and Indonesia, also show a strong commitment to this area of study. Additionally, the United States of America (USA) stands out as the principal contributor from North America, underscoring the worldwide reach and interest in AR tourism research, as noted by Zaifri et al. (2023a)

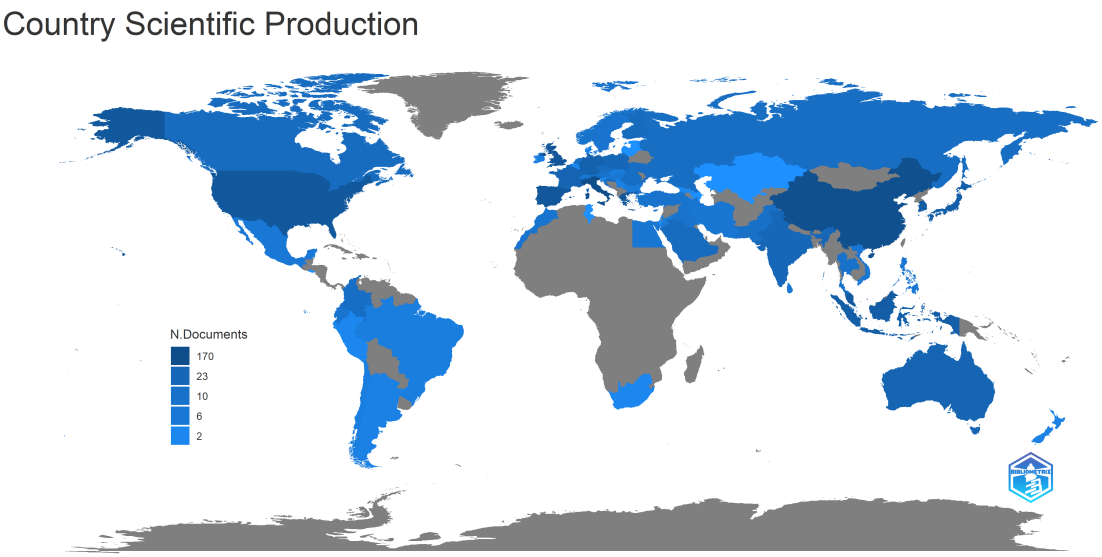


Fig. 3.3 Global Research Distribution in AR Tourism (2002-2022) by Zaifri et al. (2023a)

Zaifri et al. (Zaifri et al., 2023a) observe a diverse economic context in AR tourism research. While advanced economies like Italy, the UK, and the USA are key contributors, significant input from emerging economies such as China, Malaysia, and Indonesia highlights the field's inclusive character. This indicates that AR tourism research extends beyond economic divisions, encouraging involvement from countries at various income levels and stages of development.

Figure 3.5 presents a comprehensive analysis by Zaifri et al. (2023a) of the most cited countries in AR tourism research, illustrating a varied global representation. The United Kingdom, with 1172 citations, showcases its commitment to producing impactful AR tourism research. South Korea's 1084 citations mirror its rapid technological progress and interest in innovating AR applications for tourism. Spain and Italy, with 995 and 856 citations respectively, highlight AR's role in enhancing cultural heritage within the tourism industry. Their rich historical and cultural sites have motivated innovative AR research to augment tourist experiences. The USA, with 815 citations, reflects its status as a leader in technology and innovation. The high citation count is indicative of the substantial research contributions from its prestigious universities and research institutions.

3.3.2 Emerging Topics of AR in Tourism.

Zaifri et al. (Zaifri et al., 2023a) performed a co-word analysis on the 861 articles focused on AR applications in tourism. This analysis utilized the authors' keywords to examine the

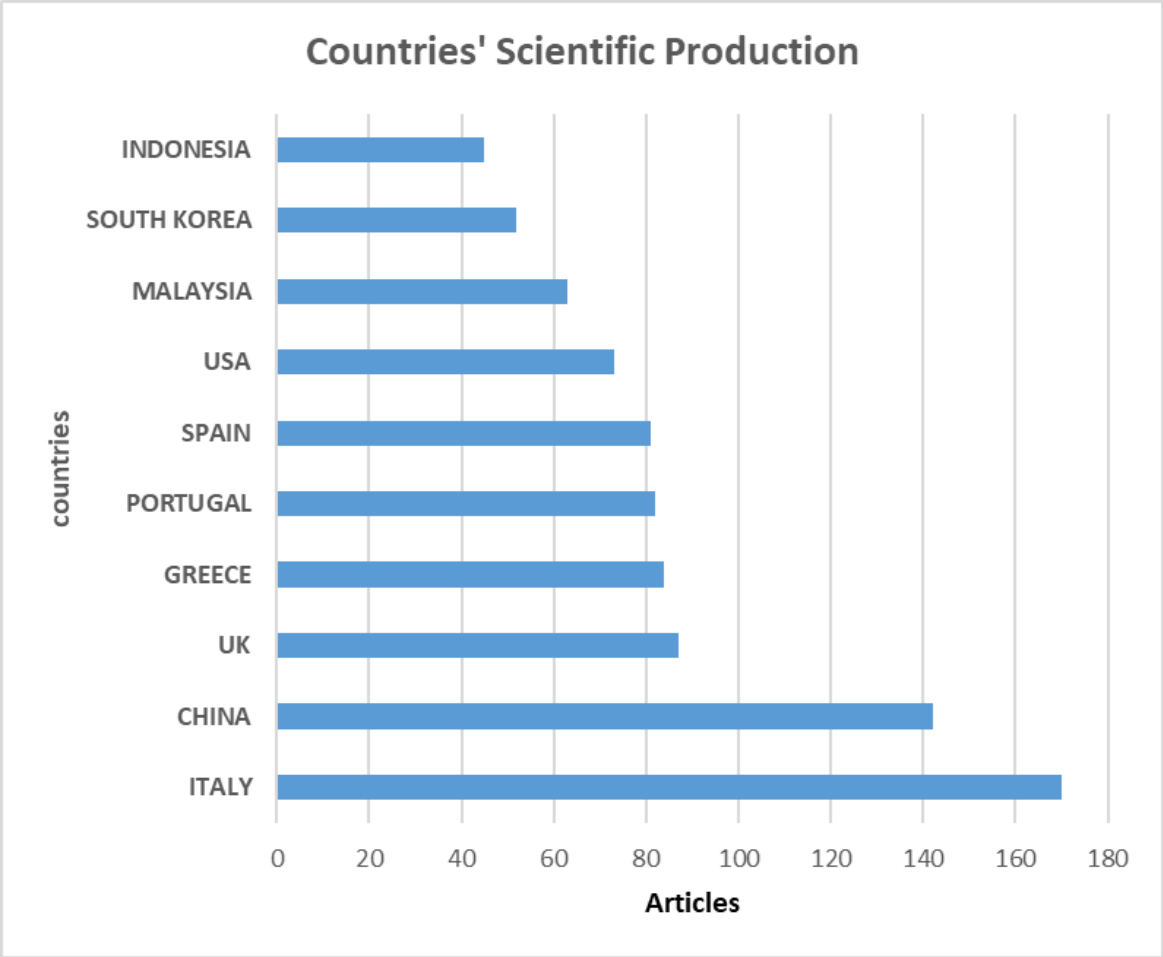


Fig. 3.4 Most Productive 10 Countries in Research Output as Determined by Zaifri et al. (2023a)

network of thematic relationships based on keyword co-occurrences, as shown in Figure 3.6. Additionally, they explored the evolution of these themes over time, as depicted in Figure 3.7.

Figure 3.6, as analyzed by Zaifri et al. (2023a), presents a visual network mapping the key concepts frequently appearing in AR tourism research. In this diagram, each node symbolizes a specific keyword, and the connections between nodes indicate how often these keywords appear together. The node size reflects the occurrence frequency of each keyword, and the link thickness denotes the association strength between them. The network is color-coded to distinguish thematic clusters, making it easier to identify prominent topics (nodes) and their interrelations (links). It's important to note that the visualization was created using the default settings and graphical parameters of the "*Biblioshiny*"[2] tool, ensuring that all nodes

[2]Biblioshiny homepage: https://www.bibliometrix.org/home/index.php/layout/biblioshiny

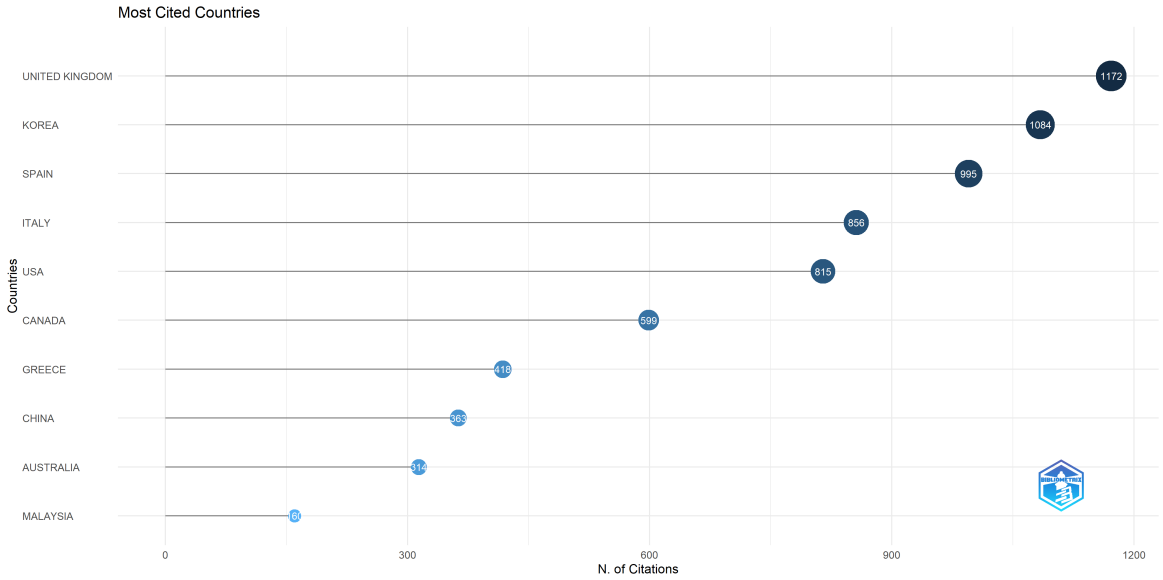


Fig. 3.5 Leading 10 Countries by Citation Count as Identified by Zaifri et al. (2023a)

maintain a minimum size for better visual clarity, irrespective of the variations in keyword occurrence frequencies.

In this review, Zaifri et al. (Zaifri et al., 2023a) identified nine thematic clusters within AR tourism research. The two most prominent clusters are 'mobile augmented reality' (MAR) and 'cultural tourism' (CT), represented by purple and orange colors, respectively. The MAR cluster, central to AR tourism research, encompasses related themes like 'image recognition', 'user experience', 'navigation', 'interaction', and 'Vuforia'. This indicates the pivotal role of MAR in this field. The CT cluster is interlinked with themes such as 'visitor experience', 'sustainability', '3D reconstruction', 'gamification', 'heritage education', and 'museums', underscoring its importance. The close ties between MAR and CT, and their overlapping sub-themes, highlight cultural tourism as a key area for MAR application, aiming to enhance tourist experiences through interactive features and heritage learning.

The 'smart tourism' (ST) cluster, marked in green, is another significant theme, closely associated with the CT cluster. It includes nodes like 'smart city', 'digital heritage', 'mobile computing', 'technology readiness', and the 'technology acceptance model' (TAM). These elements are interwoven with the CT cluster, suggesting a synergy between MAR and smart city technologies in enriching cultural tourism experiences, as explored in works like Arroyo's (Arroyo et al., 2018).

In the ST cluster, Zaifri et al. (Zaifri et al., 2023a) emphasize the critical nodes of TAM (Technology Acceptance Model) and technology readiness, underscoring the importance of understanding tourist acceptance and readiness to adopt new technologies. This understand-

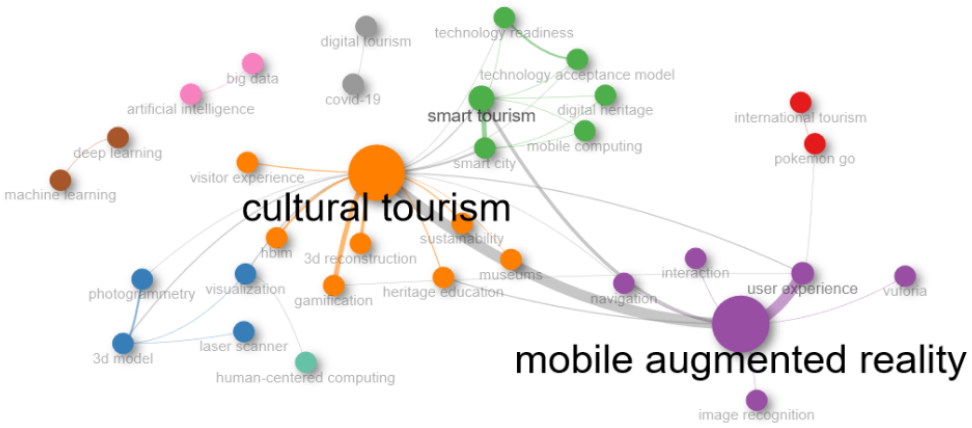


Fig. 3.6 Network of Keyword Co-Occurrences Derived from Authors' Keywords by Zaifri et al. (2023a)

ing is crucial for the effective implementation of smart 4.0 tourism solutions integrating AR technology (Sujood et al., 2022).

Additionally, the '3D visualization' cluster, depicted as the fourth blue cluster, consists of nodes like '3D model', 'photogrammetry', 'laser scanner', and 'visualization'. These nodes are closely associated with the CT cluster, highlighting the role of 3D visualization techniques in generating immersive AR experiences by creating 3D models of cultural heritage sites (Panou et al., 2018b).

Furthermore, the fifth cluster, represented by the 'human-centered computing' node and colored in sky-blue, is linked to the 3D visualization cluster. This connection emphasizes the need to consider human factors in the design and implementation of AR systems within the tourism sector (Yovcheva et al., 2014), indicating a holistic approach that blends technological innovation with human-centric design principles.

The sixth thematic cluster, identified in red by Zaifri et al. (2023a), is labeled as the 'gamification' cluster and includes the nodes 'international tourism' and 'Pokémon Go'. The link between 'Pokémon Go' and the MAR cluster via the 'user experience' node indicates the potential of AR gaming applications like Pokémon Go in attracting international tourists and enriching their tourism experiences (Aluri, 2017).

The final three clusters within the network are distinct, with no connections to the other identified clusters. The first, represented in brown, comprises two nodes: 'machine learning' and 'deep learning'. The second, in pink, consists of 'artificial intelligence' (AI) and 'big data'. The last cluster, in gray, includes 'COVID-19' and 'digital tourism'. These clusters

suggest that AI, machine learning, and digital tourism, particularly in the context of the post-COVID-19 era, may be emerging niche areas in AR tourism research that have yet to be extensively explored (Loureiro and Nascimento, 2021; Petrovic et al., 2021). These separate clusters indicate potential new directions for AR research in tourism, highlighting areas for future investigation.

Figure 3.7, by Zaifri et al. (2023a), depicts the progression of various themes in AR tourism research over time. This figure, in conjunction with Figure 3.2 showing the yearly distribution of publications, divides the period from 2002 to 2022 into five distinct phases, each representing a specific stage in the development of AR research within the tourism industry. The initial phase, termed the Pioneering Phase (2002–2006), was characterized by

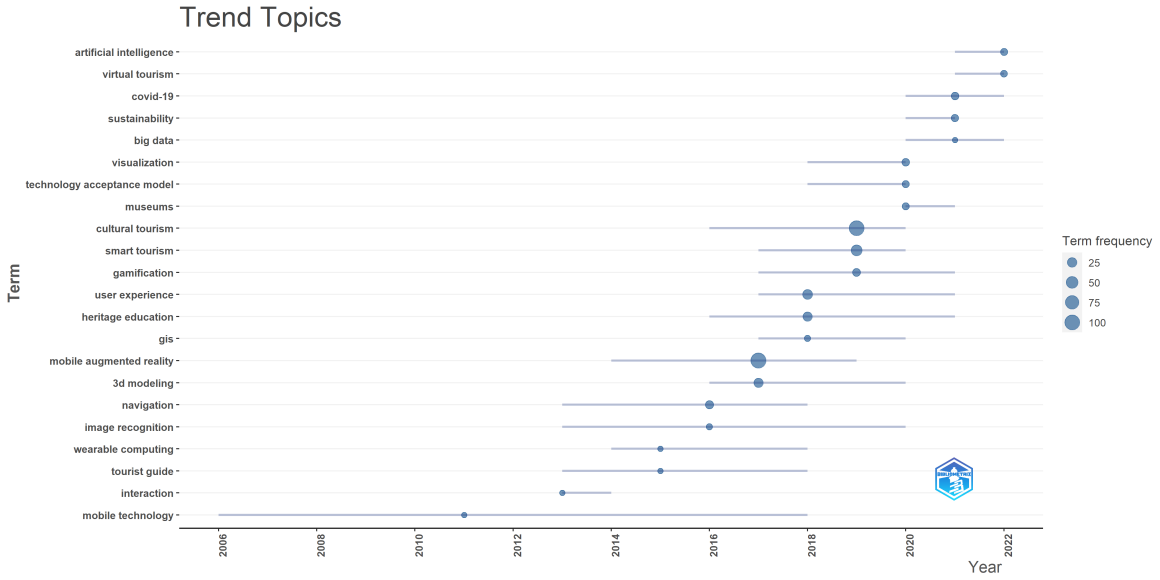


Fig. 3.7 Timeline of Keyword Occurrences and Frequencies Based on Authors' Keywords, Presented by Zaifri et al. (2023a)

a group of forward-thinking researchers investigating AR's potential in tourism, particularly concentrating on mobile technology, a key element that would gain prominence in the following years (Wolfson, 2002).

The second phase, the Mobile Engagement Era (2006–2013) highlighted the increasing significance of mobile technology in AR tourism. This period was marked by efforts to provide tourists with accessible AR experiences through handheld devices. A significant emphasis during this era was on crafting engaging and interactive AR applications to enhance the tourist experience (Hurst and van Wezel, 2011), reflecting a shift towards more user-centric AR developments in tourism.

During the third phase, termed the Technological Convergence Period (2014–2017), there was a significant emergence of wearable devices, like smart glasses, and the integration of AR with cutting-edge navigation technologies such as Geographic Information Systems (GIS). Additionally, this period saw the incorporation of advanced image processing techniques, including 3D modeling and image recognition (Mata and Claramunt, 2013). Heritage education and museums also gained notable attention during this time (Laudazi and Boccaccini, 2014), as observed by Zaifri et al. (2023a). This phase was pivotal in enhancing MAR applications, thus enabling visitors to gain a deeper understanding and appreciation of cultural tourism experiences through innovative AR solutions.

The fourth phase, identified as the User Experience Optimization Stage (2017–2019), marked a shift towards refining the user experience in AR tourism. This period focused on employing gamification strategies and advancing the concept of smart tourism (Boletsis and Chasanidou, 2018b). Research during this stage also delved into user acceptance of AR in the tourism sector, aiming to discern factors that drive user adoption and satisfaction (Obeidy et al., 2017), as noted by Zaifri et al. (2023a). Further developments in visualization techniques were undertaken to enhance the overall user experience (Hu et al., 2017). Consequently, cultural tourism saw a notable upsurge in 2019, as indicated in Figure 3.7.

The last and most recent period, the Adaptation and Integration Stage (2020–2022), marks a pivotal era in AR tourism development. This phase is distinguished by the utilization of big data to enhance AR experiences (Bermejo et al., 2017) and a growing focus on sustainability within the industry (Loureiro and Nascimento, 2021). The COVID-19 pandemic promoted the rapid adoption of AR for virtual tourism, offering innovative strategies for the sector's survival and recovery (Brozović and Saito, 2022; Franco and Mota, 2021), as observed by Zaifri et al. (2023a). Additionally, the integration of artificial intelligence into AR applications has led to more personalized and dynamic tourist experiences (Allal-Chérif, 2022), signaling a significant revolution in how AR technology is applied in tourism.

3.3.3 Most Utilized AR Design Components in Tourism Settings.

To address our third research question, Zaifri et al. (Zaifri et al., 2023a) followed the PRISMA framework to systematically identify and select 57 articles for content analysis (see Figure 3.1). These articles were published between 2013 and 2022, with 3 (5.26%) published in 2013, 2 (3.50%) in 2014, 3 (5.26%) in 2015, 3 (5.26%) in 2016, 6 (10.52%) in 2017, 13 (22.80%) in 2018, 10 (17.54%) in 2019, 6 (10.52%) in 2020, 6 (10.52%) in 2021, and 5 (8.77%) in 2022. These results suggest an increasing trend in the number of publications on AR in tourism over the years, with a significant increase in 2018. Concerning the types

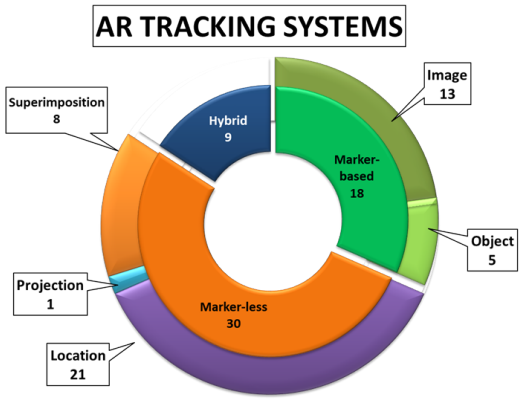
of articles, 19 papers (33.34%) were published in conference proceedings, 35 papers were journal articles (61.40%), and 3 articles were published as book chapters (5.26%). All 57 articles were written in English. The geographical distribution of the 57 articles, based on the first author's affiliation, spans four continents. Thirty-one articles are from Europe (54.39%), with countries such as the United Kingdom, Spain, Greece, France, Portugal, and others. Twenty-two articles are from Asia (38.60%), with research conducted in China, Japan, South Korea, Taiwan, the Philippines, and elsewhere. Three articles are from Africa (5.26%), with a focus on Morocco; and one article is from South America (1.75%), with a feature on Colombia. These results underscore the international traction of augmented reality in tourism, with a significant lead for Europe, followed by Asia.

AR tracking systems

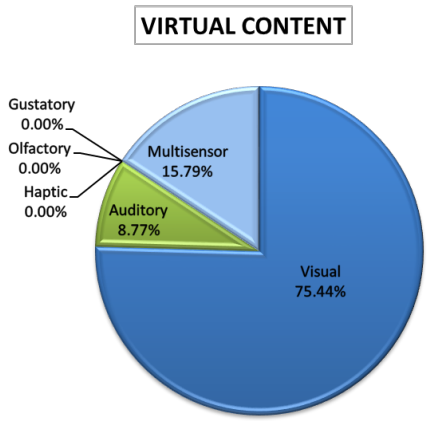
A content analysis of the 57 articles by Zaifri et al. (2023a), revealed a variety of AR systems being researched in the context of tourism. As shown in Figure 3.8a, marker-based systems, which rely on specific visual cues, such as art gallery paintings (tom Dieck et al., 2016), food menus (Pu et al., 2017), and museum artifacts (Rodrigues et al., 2019) for the accurate tracking and rendering of virtual information, account for 18 articles, with 13 focused on image-based systems, and 5 on object-based systems. Marker-less systems, which do not require predefined markers for tracking, are more prominently represented in the literature, with 30 articles in total. Among them, 21 articles explore location-based systems (e.g., (Basori et al., 2019)), 8 delve into superimposition-based systems (e.g., (Marto et al., 2021)), and only 1 investigates projection-based systems (Mendes et al., 2019). Additionally, 9 articles examine hybrid systems that combine elements from both marker-based and marker-less approaches (e.g., (Cejka et al., 2021)).

AR devices

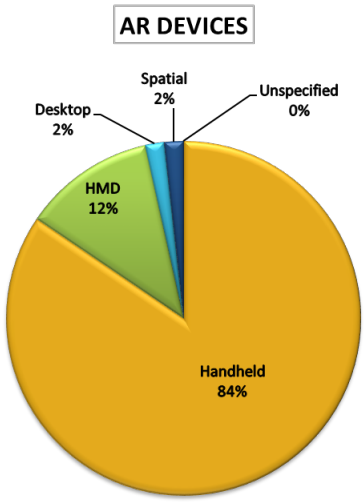
Figure 3.8c by Zaifri et al. (2023a) demonstrates the range of devices that researchers and practitioners have been exploring to deliver AR experiences in the tourism industry. Handheld devices, especially smartphones and tablets, were the most commonly used, featuring in 49 of the articles (84%). This prevalence can be attributed to the widespread accessibility and portability of mobile devices, making them a popular choice for implementing AR experiences in tourism. Head-mounted displays (HMDs), particularly smart glasses and headsets, were utilized in 7 articles (12%), offering a more immersive experience for users. Desktop systems were employed in just 1 study (2%), while spatial devices, which enable users to interact with their surroundings using video projectors (Mendes et al., 2019), also



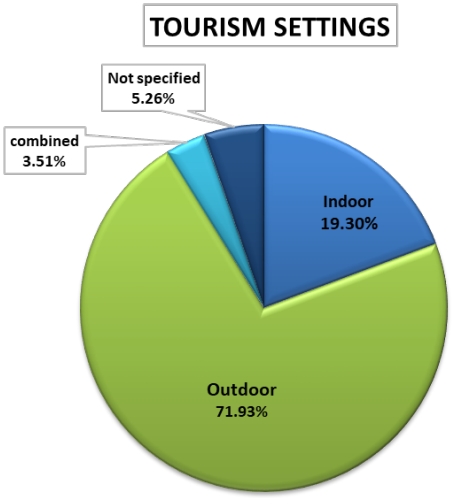
(a) AR tracking systems.



(b) Virtual content overlaid by AR devices.



(c) AR devices used to deploy AR experiences



(d) Tourism settings supported by AR technology.

Fig. 3.8 Design Components of AR in Tourism by Zaifri et al. (2023a)

appeared in 1 article (2%). Notably, none of the articles left the device type unspecified. Furthermore, the total number of articles exceeds 57, as some studies report the use of more than one AR tool.

Tourism settings

Figure 3.8d by Zaifri et al. (2023a) reveals the different tourism settings in which AR is being applied. The majority of the studies, with 41 articles (71.93%), focus on outdoor settings, highlighting the potential of AR to enhance the experience of tourists visiting natural and

urban environments (Lipianina-Honcharenko et al., 2022). In contrast, 11 articles (19.30%) explore indoor settings, such as museums, galleries, and historical buildings, demonstrating the value of AR in providing immersive experiences within confined spaces (e.g., (Shin and Choi, 2021)). Additionally, 2 articles (3.51%) investigate the combined use of AR technology in both indoor and outdoor environments, emphasizing the versatility of the technology (Amato et al., 2013; tom Dieck and Jung, 2018). It is noteworthy that 3 articles (5.26%) do not specify the tourism setting in their studies (Bibiloni et al., 2016; Lin and Chen, 2017; Pu et al., 2017).

Virtual content

The content analysis of the 57 articles, as shown in Figure 3.8b, by Zaifri et al. (2023a), reveals the various virtual content types employed in AR experiences for tourism. The most predominant type of content is visual, featured in 43 articles (75.44%), which aligns with the primary objective of AR, to overlay digital information onto the physical world. Auditory content, although less common, was employed in 5 articles (8.77%), providing an additional layer of sensory experience for users. It is intriguing to observe that none of the papers focus on haptic, olfactory, or gustatory content individually. However, 9 studies (15.79%) have developed systems that incorporate these sensory experiences simultaneously, through multi-sensor systems. For example, the system presented by Rodrigues et al. (Rodrigues et al., 2019) consists of an AR mobile application handling sight and hearing by recognizing and tracking museum artifacts, and a portable device enhancing the AR experience by stimulating touch, taste, and smell when connected to the user's mobile device.

Links between AR Tracking Systems and Tourism Settings

Table 3.6 by Zaifri et al. (2023a), presents the matrix of relationships between AR systems (rows) and tourism settings (columns), where they were employed to improve the tourist experience. Noticeable preferences for particular systems can be seen, depending on the environment. It is important to note that the total sum of articles exceeds 57, as numerous studies employ more than one system to accommodate various tourism settings. The values in parentheses correspond to the instances of the matrix.

In indoor settings, marker-based (6) and marker-less (5) systems exhibit a nearly equal distribution. Marker-based image (5) systems are the most prevalent, effectively enhancing visitor experiences by overlaying visual information onto images, making them well suited for indoor environments such as museums and galleries (Paliokas et al., 2020; tom Dieck et al., 2016). Although marker-less systems are not as popular in indoor situations, location-

based and superimposition-based applications have been found to be effective in improving user engagement in museums (Kaghat et al., 2020) and facilitating interactive experiences (Bird et al., 2022).

Outdoor settings demonstrate a clear preference for marker-less location-based applications (24). Such systems leverage the positions of users and landmarks to enrich tourism experiences, including navigation and open site exploration (Abidin et al., 2018; Chong and Alimardanov, 2021; Mendoza et al., 2015). Marker-less superimposition-based systems (10) have found more applications in outdoor settings than in indoor ones. This trend could be attributed to the growing demand for virtual tourism in the post-COVID-19 era, as these applications provide immersive experiences allowing users to explore and interact with virtual monuments in real-life dimensions (Panou et al., 2018a; Shih et al., 2019). Interestingly, marker-based image (8) and object (6) systems have also seen more frequent use in outdoor settings. This suggests that these approaches can effectively enhance visitor experiences in outdoor locations (Affan et al., 2018).

In combined indoor/outdoor settings, there is a more even distribution of AR system usage, with the marker-based image (2), marker-based object (1), and marker-less, location (1) systems being implemented. The studies in question employ a combination of systems to support different environments (Amato et al., 2013; tom Dieck and Jung, 2018). Finally, in cases where the setting is not specified, marker-based image (3) systems emerge as the most common choice. This may indicate the flexibility of certain AR systems in overcoming the limitations imposed by diverse tourism settings.

In conclusion, this analysis reveals that the choice of AR systems in tourism research is closely linked to the specific setting in which they are applied. Marker-based image systems are favored in indoor environments, while outdoor settings predominantly utilize marker-less, location-based systems. The ability of certain AR systems to function effectively in combined settings underscores their adaptability, and potential for broader applicability within the tourism sector.

Links between AR Devices and Virtual Content

Table 3.7 by Zaifri et al. (2023a), illustrates the matrix of relations between AR devices (rows) and the virtual content (columns) they produce, examining how these elements work together to improve user experience. It is important to note that the total sum of rows and columns is 59, as some projects have utilized multiple tools to provide multi-sensory content. For instance, (Litvak and Kuflik, 2020) presented two location-based AR systems that employed both smartphones and smart glasses, enabling users to access audio and visual information when arriving at a point of interest.

Table 3.6 Linkages Between AR Tracking Systems and Tourism Environments as Explored by Zaifri et al. (2023a)

	Indoor	Outdoor	Combined settings	Not specified
Marker-based image	**5** (Agustina et al., 2018; Haryani and Triyono, 2020; Paliokas et al., 2020; tom Dieck et al., 2016, 2018b)	**8** (Affan et al., 2018; Besharat et al., 2016; Dewi Agushinta et al., 2019; Gutierrez et al., 2015; Han et al., 2018; Shih et al., 2020, 2019; Tahyudin and Saputra, 2017)	**2** (Amato et al., 2013; tom Dieck and Jung, 2018)	**3** (Bibiloni et al., 2016; Lin and Chen, 2017; Pu et al., 2017)
Marker-based object	**1** (Rodrigues et al., 2019)	**6** (Cejka et al., 2021; Fino et al., 2013; Li et al., 2022; Sasaki and Yamamoto, 2019; Tatić, 2022; tom Dieck et al., 2018a)	**1** (Amato et al., 2013)	**0**
Marker-less location	**2** (Kaghat et al., 2020; Shin and Choi, 2021)	**24** (Abidin et al., 2018; Basori et al., 2019; Boletsis and Chasanidou, 2018b; Chong and Alimardanov, 2021; Han et al., 2018; Lipianina-Honcharenko et al., 2022; Mendoza et al., 2015; Panou et al., 2018a; Sasaki and Yamamoto, 2019; Tahyudin and Saputra, 2017; Yovcheva et al., 2014) (Boletsis and Chasanidou, 2018a; Chen, 2014; Chendeb et al., 2013; Demir and Karaarslan, 2018; Fakhour et al., 2020; Galih et al., 2019; Kadi et al., 2017; Litvak and Kuflik, 2020; Rezaee et al., 2021; Rokhsaritalemi et al., 2022; Wegrzyn and Moscicka, 2017) (Williams et al., 2017; Zaifri et al., 2018)	**1** (tom Dieck and Jung, 2018)	**0**
Marker-less projection	**1** (Mendes et al., 2019)	**0**	**0**	**0**
Marker-less superimposition	**2** (Bird et al., 2022; Han et al., 2019)	**10** (Boboc et al., 2019; Cejka et al., 2021; Cibilic et al., 2021; Flores et al., 2019; Huo et al., 2018; Lipianina-Honcharenko et al., 2022; Marto et al., 2021; Messelodi et al., 2015; Panou et al., 2018a; Shih et al., 2019)	**0**	**0**

Table 3.7 Connections Between AR Devices and Virtual Content as Analyzed by Zaifri et al. (2023a)

	Visual	Auditory	Haptic	Olfactory	Gustatory	Multi-sensory
Handheld	**39** (Abidin et al., 2018; Amato et al., 2013; Basori et al., 2019; Bibiloni et al., 2016; Cejka et al., 2021; Lin and Chen, 2017; Lipianina-Honcharenko et al., 2022; Mendoza et al., 2015; Paliokas et al., 2020; Pu et al., 2017; Shin and Choi, 2021; Yovcheva et al., 2014) (Affan et al., 2018; Agustina et al., 2018; Besharat et al., 2016; Dewi Agushinta et al., 2019; Fino et al., 2013; Haryani and Triyono, 2020; Li et al., 2022; Panou et al., 2018a; Sasaki and Yamamoto, 2019; Shih et al., 2020, 2019; Tahyudin and Saputra, 2017) (Chen, 2014; Chendeb et al., 2013; Demir and Karaarslan, 2018; Galih et al., 2019; Kadi et al., 2017; Rezaee et al., 2021; Rokhsaritalemi et al., 2022; Tatić, 2022; Wegrzyn and Moscicka, 2017; Williams et al., 2017; Zaifri et al., 2018) (Cibilic et al., 2021; Flores et al., 2019; Huo et al., 2018; Messelodi et al., 2015)	**2** (Boletsis and Chasanidou, 2018b; Chong and Alimardanov, 2021)	**0**	**0**	**0**	**8** (Boboc et al., 2019; Gutierrez et al., 2015; Han et al., 2018; Litvak and Kuflik, 2020; Marto et al., 2021; Rodrigues et al., 2019; tom Dieck and Jung, 2018; tom Dieck et al., 2018a)
HMD	**3** (Bird et al., 2022; tom Dieck et al., 2016, 2018b)	**3** (Boletsis and Chasanidou, 2018a; Fakhour et al., 2020; Kaghat et al., 2020)	**0**	**0**	**0**	**2** (Han et al., 2019; Litvak and Kuflik, 2020)
Desktop	**1** (Chendeb et al., 2013)	**0**	**0**	**0**	**0**	**0**
Spatial	**1** (Mendes et al., 2019)	**0**	**0**	**0**	**0**	**0**

The matrix indicates that users are primarily attracted to handheld devices, such as smartphones, tablets, or even portable telescopes, as demonstrated by (Chendeb et al., 2013), for creating various types of virtual content. A substantial emphasis is placed on visual (39) and multi-sensory (8) content. For example, users were able to employ their smartphones to superimpose 3D models of historical monuments in accurate dimensions (Amato et al., 2013; Panou et al., 2018a), or navigate to points of interest using annotations or virtual paths projected onto the real world (Galih et al., 2019; Lipianina-Honcharenko et al., 2022; Yovcheva et al., 2014). Tourists could also generate 3D reconstructions of historical sites that are submerged underwater (Cejka et al., 2021). These results are consistent with the emergence of mobile AR as a central topic in AR tourism research.

HMDs, on the other hand, are predominantly utilized for visual content (3), with smart glasses enabling users to interact with 3D animations (Bird et al., 2022), or enhance learning experiences at art galleries (tom Dieck et al., 2018b). Similarly, HMDs are employed for auditory content (3), with headsets serving as audio AR tour guides in indoor museums (Kaghat et al., 2020) and outdoor environments (Boletsis and Chasanidou, 2018a; Fakhour et al., 2020). HMDs have also been used for multi-sensory content (2), incorporating smart glasses with audio output, to facilitate exploration and navigation of historic sites (Litvak and Kuflik, 2020). This evidence demonstrates that researchers are actively pursuing more immersive AR experiences through HMDs, even though handheld devices currently dominate the research landscape.

Regarding desktop and spatial devices, both have a very limited representation, with each being used only once for generating visual content. This could be attributed to the fact that desktop and spatial devices, such as AR projectors, are less practical, and have limited sensor capacities for AR application in tourism. As a result, researchers and practitioners may be less inclined to explore these devices in the context of AR tourism for enhancing user experiences, instead focusing on more portable and versatile options such as handheld devices and HMDs.

3.4 Future Directions

Based on the above findings, Zaifri et al. (2023a) thoughts on the future directions of AR in tourism are as follows:

- **Artificial intelligence (AI) and machine learning in AR**: Recent research initiatives have delved into the use of AI and machine learning to develop more tailored and dynamic tourism experiences (Basori et al., 2019). Zaifri et al. (Zaifri et al., 2023a)

suggest that incorporating deep learning algorithms could lead to AR content customization based on individual user needs, thereby crafting engaging experiences aligned with user preferences, behaviors, and patterns. Future research might focus on integrating generative AI models, which could enhance user interaction through natural language processing (NLP) and streamline AR content creation. Utilizing generative AI in AR applications promises more intuitive and fluid experiences, while also potentially reducing the time and resources required for developing content.

- **Big data analytics in AR**: Rezaee et al. (Rezaee et al., 2021) highlight a key challenge in AR adoption for tourism: the scarcity of requisite data resources despite the daily generation of vast amounts of spatial data by individuals. Zaifri et al. (2023a) emphasize that leveraging big data analytics could substantially enrich AR experiences. By accessing real-time data on tourists, destinations, and other pertinent aspects, big data analytics can enhance decision-making processes, refine user recommendations, and improve the overall quality of AR content tailored for tourists.

- **Emphasis on sustainability**: In an era where sustainability is increasingly vital, AR applications have the potential to significantly contribute to educating tourists about the importance of conserving natural and cultural heritage while reducing environmental footprints. As pointed out by Zaifri et al. (2023a) and Loureiro et al. (Loureiro et al., 2020), superimposition-based AR systems can offer virtual experiences of historic sites, eliminating the necessity of physical presence. This approach could alleviate sustainability challenges associated with the high mobility of tourist groups in conventional tourism.

- **Integration of Internet of Things (IoT)**: The bibliometric analysis conducted by Zaifri et al. (2023a) indicates an increasing emphasis on smart tourism, particularly in the realm of smart cities combined with AR. As IoT technologies evolve, future research should explore how AR can be integrated with IoT to deliver real-time information on public transportation (Pokric et al., 2014), events, and various services. This integration can simplify navigation and exploration for tourists, thereby enhancing their experience and broadening the scope of AR in smart tourism solutions.

- **Wearable AR development**: Zaifri et al. (Zaifri et al., 2023a) suggest that future research should place a greater emphasis on wearable AR technologies. Their systematic review revealed that a vast majority (84.84%) of studies focused on AR experiences via handheld devices, while only a smaller fraction (12.07%) employed Head-Mounted Displays (HMDs). This trend points towards a shift in focus to HMDs, which are

expected to provide a more immersive user experience. Consequently, the field may see the development and popularization of comfortable, affordable, and user-friendly wearable AR devices like glasses (Perry, 2021) and headsets. Such advancements could significantly enhance the adoption of AR technology by tourists.

- **Expanding sensory AR experiences**: The research reviewed by Zaifri et al. (2023a) indicates a current shortfall in AR technology's support for haptic, olfactory, and gustatory experiences in tourism. This gap may stem from technological constraints, accessibility issues, and user receptivity. To bridge this divide, future research could focus on the development, implementation, and evaluation of AR applications incorporating these sensory modalities in tourism settings. By integrating a range of sensory inputs, multimodal AR has the potential to significantly enhance the immersion and overall experience of tourists.

- **Virtual and remote tourism**: The post-COVID-19 era has seen an escalating demand for virtual and remote tourism experiences, as noted by Zaifri et al. (2023a) and highlighted in Akhtar's work (Akhtar et al., 2021). Future research in this area could focus on filling this need by creating immersive and interactive AR experiences. These developments would enable tourists to virtually explore and learn about destinations without the requirement of physical travel, potentially revolutionizing the way people experience tourism in a world still adapting to the impacts of the pandemic.

- **User experience optimization**: As projected by Zaifri et al. (2023a), forthcoming AR research in tourism is expected to concentrate on refining user experience (UX) optimization. This could involve a broader application of gamification strategies, enhanced navigation capabilities in various environments, and customizable interfaces tailored for users with disabilities. Additionally, as underscored in their chapter, AR in tourism is a global phenomenon (as shown in Figure 3.2). Therefore, future AR solutions should be designed to support multicultural experiences, thereby accommodating the diverse cultural needs and preferences of an international tourist demographic. This approach will help ensure AR tourism applications are inclusive and appealing to a wide spectrum of global users.

3.5 Limitations and Perspectives

While Zaifri et al. Zaifri et al. (2023a) employed a thorough methodology in this chapter, certain limitations are noteworthy. First, the review was confined to English-language articles,

possibly introducing a language bias and excluding pertinent research in other languages. Future studies could broaden the review's scope to encompass non-English literature for a more comprehensive understanding of AR's application in tourism.

Second, the research relied solely on Scopus and Web of Science for data collection. Although these databases are extensive, they may not encompass all relevant studies, particularly those in other databases or in gray literature. Future research should consider including additional databases and sources to ensure a more exhaustive collection of relevant studies.

Third, the chapter's approach combined bibliometric and systematic content analysis to investigate AR in tourism. While these methods offer valuable insights, they have inherent limitations. Co-word analysis depends on keyword frequencies, which can be influenced by author preferences and changes in terminology. Systematic content analysis, being subjective, might reflect researchers' interpretations and biases. To corroborate and enhance these findings, future studies could integrate methods like meta-analysis.

3.6 Conclusion

In this chapter, Zaifri et al.Zaifri et al. (2023a) conducted a comprehensive literature review on AR in tourism from 2002 to 2022. Through bibliometric and systematic content analysis, they revealed the development and contexts of AR in tourism and identified key design elements enhancing tourist experiences. Figure 3.9 summarizes the methods and findings. The review shows increasing interest in AR for tourism since 2008, with Europe and Asia leading research efforts.

Key themes identified in 861 papers are mobile AR, cultural tourism, and smart tourism. The evolution of AR research shifted from initial explorations to a focus on user experience and recent adaptations integrating technologies like AI and big data. Sustainability and virtual tourism have gained importance due to the COVID-19 pandemic.

The analysis of 57 articles shows a preference for marker-less, location-based AR systems using handheld devices. Research primarily focuses on outdoor tourism, with significant application in indoor settings like museums. Visual and auditory contents are prevalent, with emerging studies on multi-sensor systems incorporating various sensory experiences.

Future research directions in AR tourism highlighted by Zaifri et al. (2023a) include developing multimodal experiences, integrating AI and big data, supporting sustainability, and expanding virtual-remote tourism. There's also a focus on wearable AR technology and user experience optimization to accommodate diverse tourist needs and foster multicultural engagement.

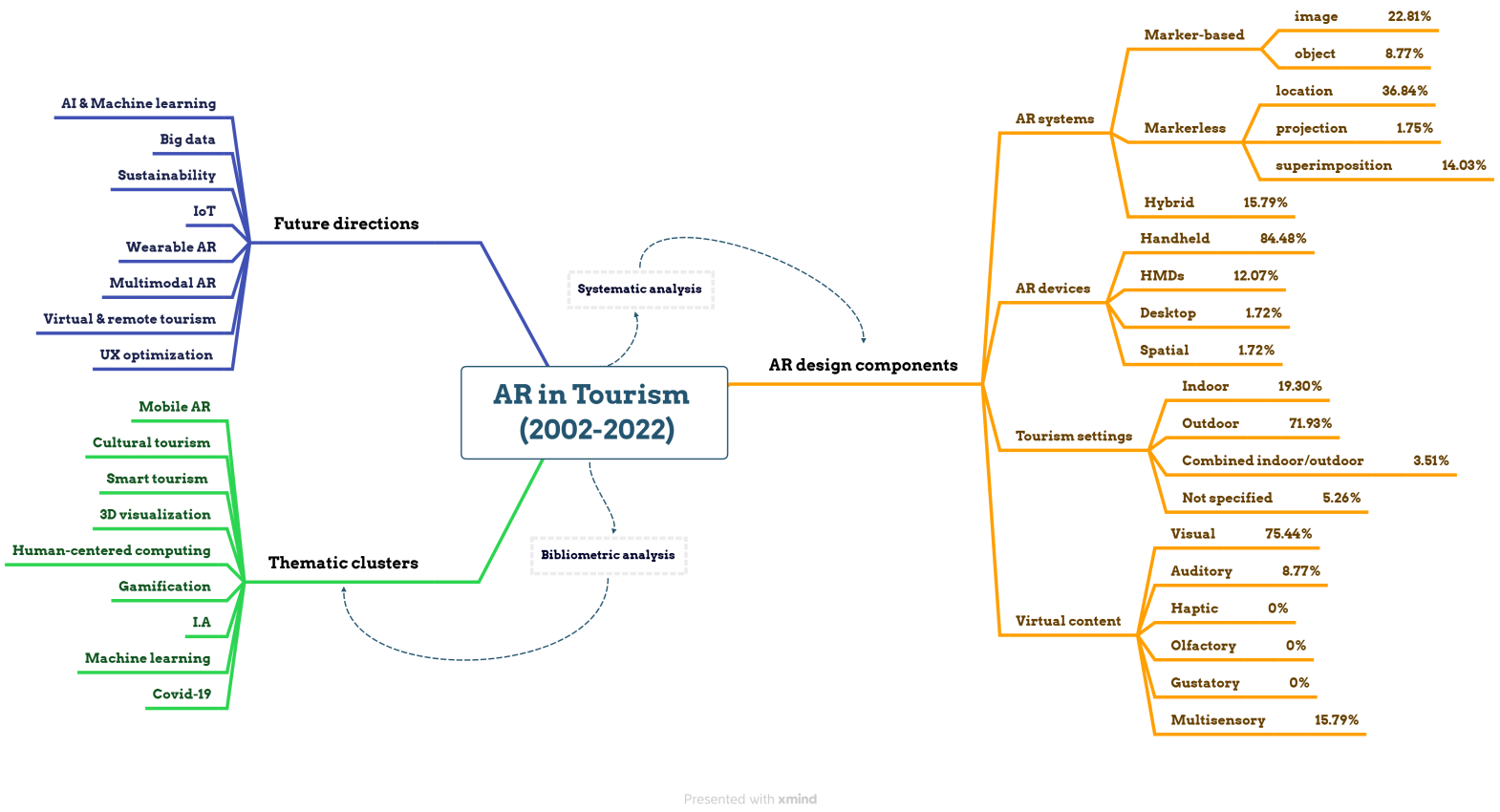


Fig. 3.9 Methodological Overview and Key Findings Summary by Zaifri et al. Zaifri et al. (2023a)

Chapter 4

Design and development of FEZAR

4.1 Introduction

AR localization-based applications are being explored in the tourism sector to improve the experience of tourists. They do not only provide useful information on places of interest, but also propose to customize this information according to the user's preferences (Chen, 2014). Enhanced visualization reduces the mental effort required for navigation and allows travelers to discover tourist routes using vocal or visual representation and 3D shapes (Kourouthanassis et al., 2015).

In this chapter, we aim to introduce the design and development of a novel conceptual framework for a personalized, location-based AR system. Our framework effectively leverages both user context and behavior to predict interests and recommend a personalized itinerary for tours of cultural heritage sites. User context is inferred from demographic profile and spatiotemporal situation, whereas user behavior is measured from interaction with specific points of interest (POIs). The framework we propose recommends POIs to a visitor by calculating and updating their interest score based on their interaction throughout the visit, thus promoting a dynamic and personalized tourism experience.

The following sections of this chapter are organized as follows: the next section offers an in-depth description of the conceptual framework proposed for the FEZAR model (see Section 4.2). Next, we highlight the key elements that were essential in transforming significant segments of the framework into an operating mobile prototype (see Section 4.3). The chapter concludes with a discussion of the avenues and ideas that have emerged from this research and some perspectives for improvement in the section 4.4.

4.2 Personalized AR Framework

The proposed framework architecture, as illustrated in Figure 4.1, is constructed from three central models. First, **the Visit Model** that encompasses the physical, virtual, and semantic dimensions of a user's visit. Second, **the Visitor Model**, dedicated to capturing and storing user profiles and behavioral data to understand their preferences and interests. Last, **the Interaction Model** that facilitates the interplay between the Visitor and Visit Models through three modes, namely, Tracking, Control, and Adaptation.

4.2.1 The visit model

As shown in Figure 4.2, the visit model enables tourist visits to be structured in three layers: the physical layer (historical sites), the virtual layer (AR objects), and the semantic layer (semantic tags). These three layers work in combination to create a comprehensive and immersive visit model.

The physical layer

This layer represents the physical environment in which visitors can freely navigate and engage with the system. It encompasses all the geometric details of the physical space and its constituent objects. In the context of historic sites located in an open environment, the physical layer is responsible for capturing and representing the geospatial information

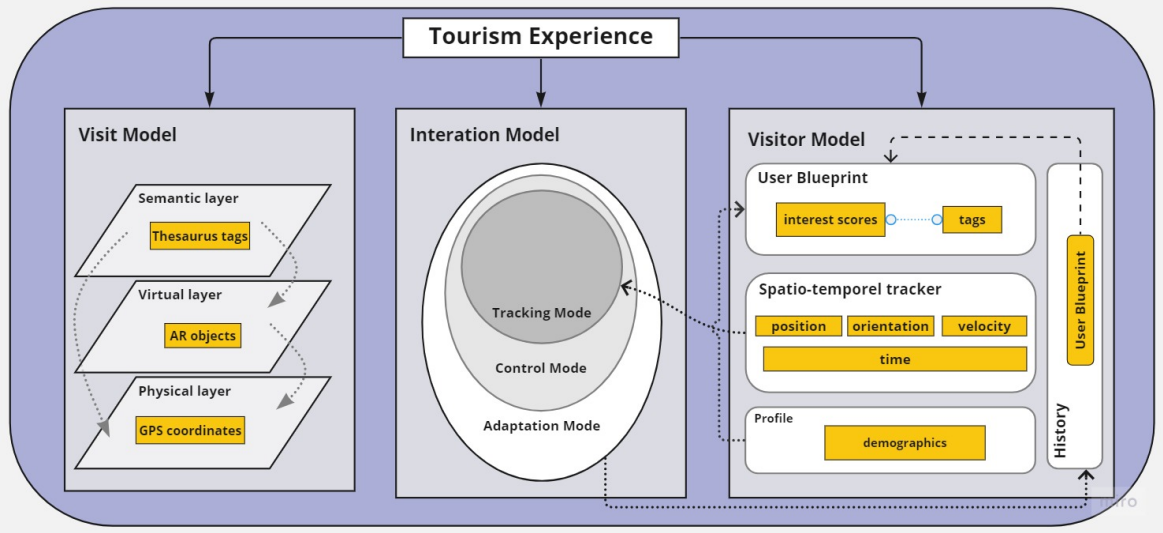


Fig. 4.1 Schematic Overview of the Proposed Framework Design.

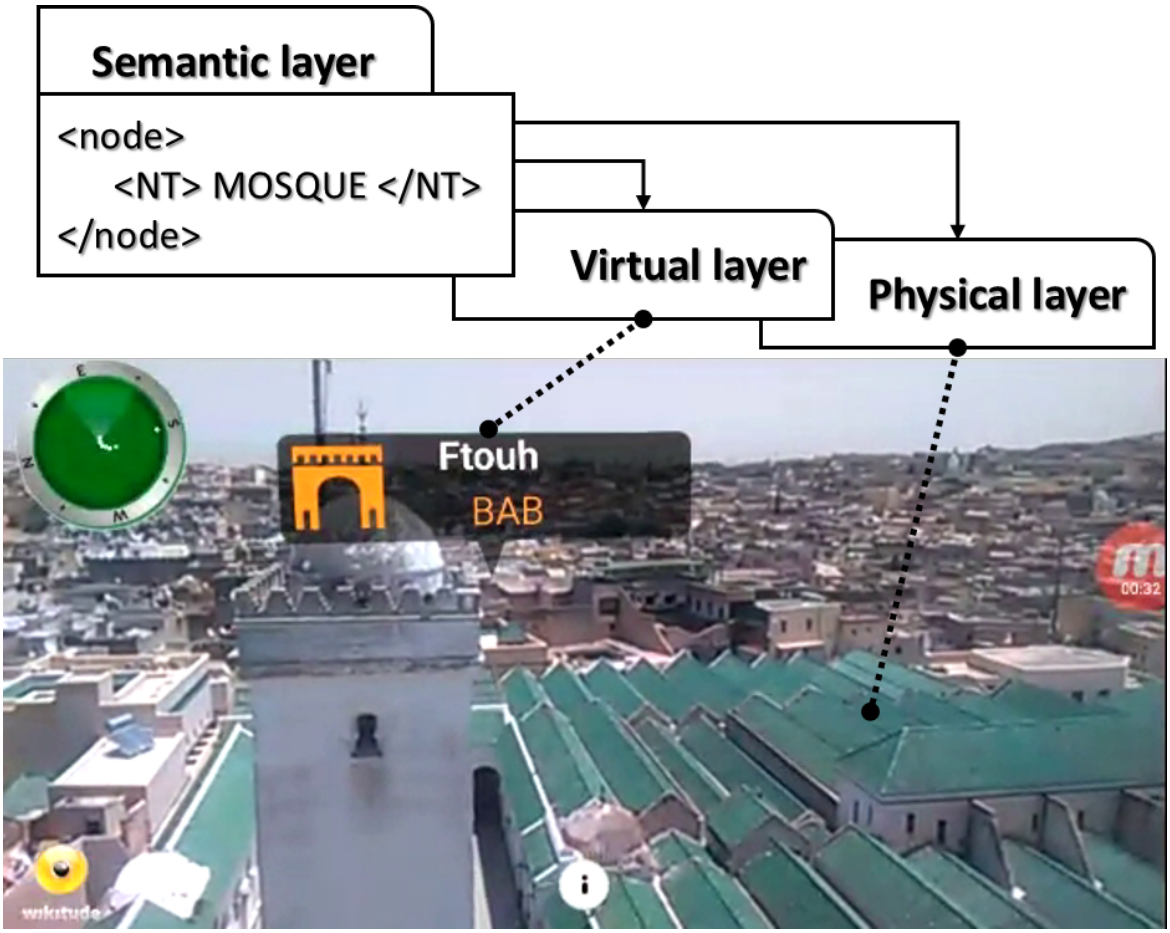


Fig. 4.2 Illustration of the Visit Model Layers in the FEZAR Application (Zaifri et al., 2018).

associated with each POI, such as geographic coordinates and other relevant spatial attributes that define and contextualize historic sites in physical space.

The virtual layer

By incorporating geospatial information of the physical layer, the system ensures accurate positioning and presentation of historic sites to visitors as part of the AR experience. In conjunction with AR technology, the physical layer is further enhanced by the inclusion of AR objects representing each POI. When selected, these AR objects provide essential details, including text description, associated images, POI name, type, and distance. With precise user tracking, AR objects are dynamically aligned to the user's position and orientation.

The semantic layer

The virtual and physical layers are further enriched by a semantic layer, which employs a set of semantic labels to give context to both the AR objects and historical sites. To enhance the annotation system and address the potential ambiguity in natural language, we leverage the use of a thesaurus when tagging POIs that could potentially have similar characteristics shared by various historical sites. By employing a thesaurus, we ensure standardized usage of words within our tags and establish explicit relationships between associated concepts (tags) (ISO_25964-2, 2013). As the thesaurus used will be developed for a limited number of objects, we could rely primarily on hierarchical relationships to link terms (see Figure 4.3).

4.2.2 The visitor model

The term "visitor" encompasses both ordinary tourists as well as advanced users, such as tour guides, who are potential users of the interface. The visitor model comprises two levels: the pre-visit sub-model and the in-visit sub-model.

At the pre-visit sub-model level, the visitor is represented by their profile, which consists of demographic data and personal preferences. This profile provides a baseline understanding of the visitor's background and interests prior to their visit. The in-visit sub-model captures

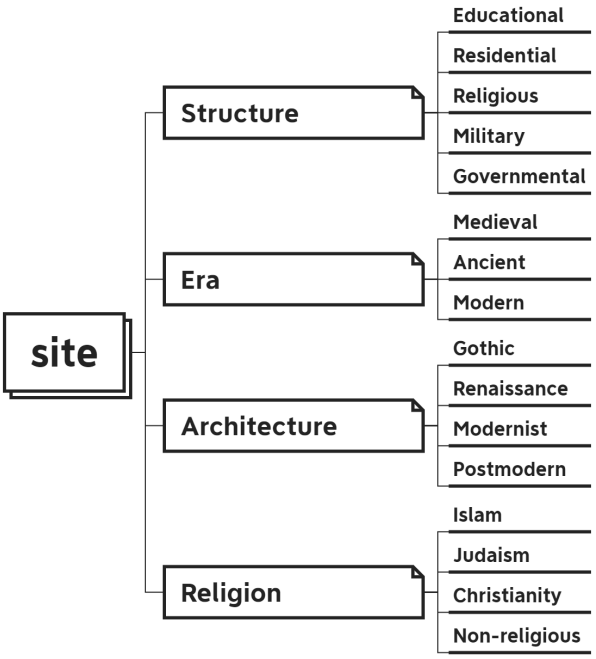


Fig. 4.3 Thesaurus Sample Illustration

the visitor's behavior during their visit, including stops, distance traveled, speed, AR objects consulted, and time spent reading POI descriptions. This sub-model continuously updates the visitor's centers of interest based on their real-time actions and interactions.

Pre-visit sub-model: user profile

Prior to the initial visit, visitors are guided through a two-stage process to create their user profile. In the first stage, visitors are requested to provide basic information such as their age, gender, language, and level (whether they are tourists or guides). In the second stage, visitors are further prompted to indicate their preferences, specifically the types of monuments they prefer to explore. Based on the data gathered from these two forms and the visitor's current position, the system generates an initial route highlighting potential POIs tailored to the visitor's profile.

In-visit sub-model: user behavior

The in-visit sub-model is an integral part of our approach, as it captures visitor behavior during their visit to historical sites. It tracks actions such as stops, distances traveled, speed, AR objects selected, and time spent reading descriptions. This real-time data enables the system to dynamically adjust AR object presentation and offer personalized adaptation of the visitor experience. This could be achieved by integrating three key components: Spatiotemporal Tracker, User Blueprint, and History.

1. **Spatiotemporal Tracker:** At its core, spatiotemporal tracking involves continuously determining the position, orientation, and velocity of a user in real time. Utilizing the built-in GPS and motion sensors in a user's device, it's possible to discern the precise location, field of view, and speed of the user's movement. In mathematical terms, the location of a user at any given time 't' is represented as a tuple of GPS coordinates $(x(t), y(t), t)$. Here, $x(t)$ and $y(t)$ correspond to the latitude and longitude respectively at the timestamp 't'.

   Given the user's location, the distance to a selected POI can be calculated, resulting in a time-dependent distance series $D(t)$. This is done using *the haversine formula* (Chopde and Nichat, 2013; Dauni et al., 2019).

$$D(t) = 2R\sin^{-1}\left(\sqrt{\sin^2\left(\frac{x_2(t)-x_1(t)}{2}\right) + \cos\left(x_1(t)\right)\cos\left(x_2(t)\right)\sin^2\left(\frac{y_2(t)-y_1(t)}{2}\right)}\right) \tag{4.1}$$

Here R is the given Earth's radius (6371 km), while $(x_1(t), y_1(t))$ and $(x_2(t), y_2(t))$ refer to the latitude and longitude of the user and POI at time 't' respectively.

Having the series of distances over time, we can then calculate the user's average velocity $V(t)$ at any time 't' via the formula :

$$V(t_i) = \frac{D(t_i) - D(t_{i-1})}{t_i - t_{i-1}} \tag{4.2}$$

This formula calculates the average velocity of the user based on the change in time and displacement related to distance from monuments. Considering the user's direction with respect to a POI, determined by the sign of the velocity, the system can assume if the user is stationary, approaching/departing, or running/walking.

2. **User Blueprint:** The objective is to build a tailored navigation map by defining a list of POIs for every individual user. This personalized list, which we term as the "User Blueprint", is created by attributing a score between 0 and 1 to each semantic

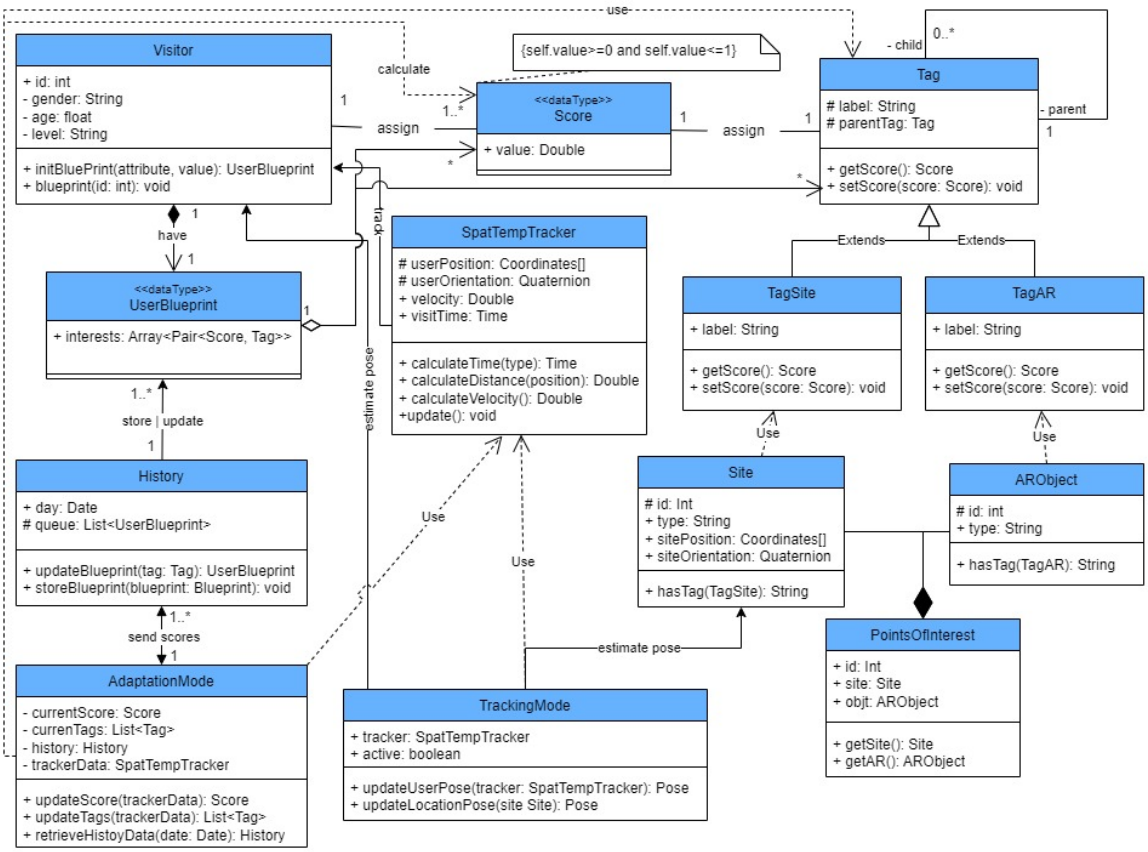


Fig. 4.4 Class diagram of the proposed framework

tag that's associated with an AR object or a historic site. Thus, in this framework, the User Blueprint can be expressed as a list of pairs where each pair contains a tag and its corresponding score.

$$UB(id) = \{(tag_1, score_1), (tag_2, score_2), \ldots, (tag_i, score_i)\} \tag{4.3}$$

Initially, the score is established based on the user's profile in the pre-visit sub-model. It is then dynamically updated during the visit, reflecting the user's interactions with specific POIs in the in-visit sub-model.

3. **History:** The 'History' function in our proposed framework serves two main purposes. Firstly, it plays a real-time role in updating the 'User Blueprint' with interest scores observed by the Adaptation Mode, which is dictated by the user's interaction with tagged POIs. Secondly, it is responsible for preserving the past interest score from the previous day (i.e. visit, session), thereby avoiding a system reset of the score in the following day. In essence, this ensures the system is always attuned to the user's current and past preferences, ensuring continuity in the user experience.

4.2.3 The interaction model

This last component, the interaction model, serves as the bridge between the visit model and the visitor, facilitating various interaction modes between them. The interaction complexities span from basic analysis of the visitor's position and orientation (in tracking mode) for scene augmentation with virtual elements, to real-time tour adaptation (in adaptation mode) based on the visitor's behavior. Figure 4.4 depicts the various relationships between these modes and other system classes, including the spatiotemporal tracker, user blueprint, the visitor, and the POIs.

Tracking mode

In the Tracking Mode of the Interaction Model, the visitor navigates historical sites, interacting with the physical landscape. The visitor's position, orientation, and velocity are captured through sensor tracking in the Spatiotemporal Tracking component. This data serves as inputs to estimate their pose via Camera Pose Estimation. Subsequently, the Tracking Mode enables the system to deliver AR content. This content adapts to the historical sites' Pose, determined through Object Pose Estimation, as depicted in Figure 4.5. Pose estimation enables the system to understand the visitor's spatial context and angle of view, which is essential for presenting AR content that aligns with their perspective and movement (Seo

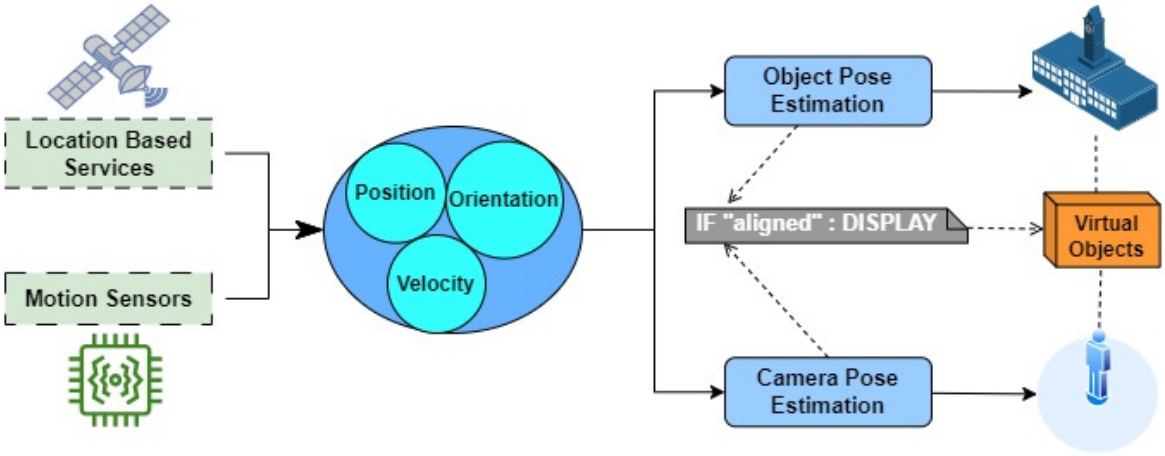


Fig. 4.5 Illustration of the tracking mode in our proposed framework using Pose Estimation

et al., 2010). This type of pose estimation is commonly used by location-based AR browsers dedicated to city tourist guidance, which has significantly contributed to the early success of AR (Pagani et al., 2016).

Control mode

Within the framework we are proposing, the control mode serves as a customization layer located between the tracking mode and the adaptation mode. Its main purpose is to avoid the "all-or-nothing" approach of automated systems, by giving users the ability to customize their AR experience. Specifically, in the control mode, users are provided with a panel that allows them to define the distance at which POIs are displayed, as well as to choose the types of monuments that interest them most, as illustrated in Fig. **??**. This mode could then inform the adaptation mode, filtering out POIs that don't meet user-defined criteria, and the adaptation mode could continue to refine the user experience based on their engagement with the filtered POIs. To highlight the difference between the two concepts of personalization and customization, the researchers consider personalization to be an automated process driven by the system, while customization is seen as a process initiated by the user (Salonen and Karjaluoto, 2016).

Adaptation mode

The second mode in the interaction model is known as the "*Adaptation Mode*", which plays a key role in personalizing the AR experience for users. Its primary function is to determine the inclusion or exclusion of specific POIs in a user's itinerary (i.e. User Blueprint). Through

continuous updating, the adaptation mode adds, deletes, or maintains POIs based on their relevance to the user's behavior.

This continuous updating process involves recalculating scores of interest corresponding to a set of semantic tags, using the provided formulas. The decision to add or delete a POI is contingent on its score, which must exceed or fall below a predetermined threshold value.

1. **Interest score calculation**

   Given a historic site 'S' and an AR object 'O' associated to a POI:

   • $Tags(S) = ts_1, \ldots, ts_i$ are the predefined thesaurus-based tags associated with S.

   • $Tags(O) = to_1, \ldots, to_i$ are the predefined thesaurus-based tags associated with O.

   • Nt_O represents the total number of tags associated with O.

   • Nt_S represents the total number of tags associated with S.

   In the context of a user, denoted as 'U':

   • $Score(U, POI)$ is the score of interest of a $'U'$ towards a POI.

   • $Score(U, S)$ is the score of interest of a $'U'$ towards a historic site.

   • $Score(U, O)$ is the score of interest of a $'U'$ towards an AR object.

   • $Score(U, t)$ is the score of interest of a $'U'$ towards a tag.

   • $Score_0(U, t)$ is the initial score of interest towards a tag based on $'U'$ profile.

   Assuming that S and O contribute equally to the visitor's interest in a POI, and recalling that the scores value varies from 0 to 1:

$$\text{Score}(U, POI) = \begin{cases} \frac{\text{Score}(U,O)+\text{Score}(U,S)}{2}, & Nt_0 \neq 0 \text{ and } Nt_s \neq 0 \\ \text{Score}(U, S), & Nt_o = 0 \text{ and } Nt_s \neq 0 \\ S\text{core}(U, O), & Nt_0 \neq 0 \text{ and } Nt_s = 0 \\ 0, & Nt_0 = 0 \text{ and } Nt_s = 0 \end{cases} \tag{4.4}$$

   The score of interest of a historic site (resp. AR object) is calculated as the mean of the visitor interest score to all the tags associated to that historic site (resp. AR object).

$$\text{Score}(U, S) = \frac{\sum_{i=1}^{Nt_s} \text{Score}\,(U, ts_i)}{Nt_s} \tag{4.5}$$

$$\text{Score}(U, O) = \frac{\sum_{i=1}^{Nt_o} \text{Score}\,(\text{U}, \text{to}_\text{i})}{Nt_o} \tag{4.6}$$

As the "$Score_0(U,t)$" is established based on the user profile, it is utilized later to update "$Score(U,t)$" according to the appreciation or depreciation of a historic site (resp. AR object) by a visitor.

In accordance with the recommendation of Pazzani et al. (Pazzani and Billsus, 1997), the system assumes that the level of visitor interest in a historic site or AR object is correlated with the amount of time they spend interacting with it.

Given a duration T spent by a visitor interacting with an AR object or at a historic site, and T_{tsh} is a predefined threshold.

Algorithm 1 Pseudocode Sample for POI Score Adjustment based on spatiotemporal tracking and user behavior (interaction)

Require: $T_{\text{TSH}} = 30$, $L \leftarrow 10$
Ensure: $T \geq 0$, location_services $\leftarrow$ True

```
while System is Running do
    for each poi do
        if (D(t_k) ≤ 2 and V(t_k) = "STOP") or (AR_Object(i) = "selected") then
            T ← 'interaction duration'
            if T ≥ T_TSH then
                APPRECIATE_POI
            else if T < T_TSH then
                DESPRECIATE_POI
            end if
        end if
    end for
    wait for L
end while
```

2. **Item appreciation**

   At any given time, if $T \geq T_{tsh}$ then AR object (resp. a historic site) has been appreciated, and the interest score of the associated tags is increased as follows:

$$\text{Score}_i(U,t) = \text{Score}_{i-1}(U,t) + \frac{1 - \text{Score}_0(U,t)}{\sum(\text{POIs tagged by } t)} \tag{4.7}$$

3. **Item depreciation:**

   On the other hand, if $T < T_{tsh}$ then AR object (resp. historic site) has been depreciated, and the interest score of the associated tags is devalued as follows:

$$\text{Score}_i(U,t) = \text{Score}_{i-1}(U,t) - \frac{1 - \text{Score}_0(U,t)}{\sum(\text{POIs tagged by } t)} \tag{4.8}$$

The pseudo-code depicted in Algorithm 1 outlines the operational flow of interest score adjustment in our proposed framework. The system evaluates user interaction with each POI in real time, considering both physical proximity and AR object selection. It uses thresholds to determine whether to appreciate or depreciate a POI based on the duration of the user's engagement.

4. **User blueprint update:**

   As previously mentioned, the decision to include or remove a POI from the User Blueprint depends on its score, which must either surpass or fall below a predefined threshold value. This is done in the History module.

   Recalling that: $0 \leq Score(U, POI) \leq 1$, We define two thresholds: $MIN_{interest}$ and $MAX_{interest}$.

   The objective is to create three distinct ranges of the interest score that are continuously defined for each visitor, and to update the tour according to these intervals:

   - $[0; MIN_{interest}]$: POI is removed from the visitor itinerary.
   - $]MIN_{interest}; MAX_{interest}[$: POI is kept in the visitor itinerary.
   - $[MAX_{interest}; 1]$: POIs is included in the visitor itinerary.

In summary, our proposed system architecture comprises three integral models: the visit model, visitor model, and interaction model. Each of these models incorporates the necessary layers and key characteristics of a personalized, location-based AR interface, for tourist experiences in outdoor environments. The process flow shown in Figure 4.6 illustrates how these core models work together in our proposed framework to capture user behavior and preferences, providing them with POI-based AR landmark recommendations.

4.3 Development of Mobile AR tour guide

4.3.1 MAR platforms and libraries

Developing a location-based MAR framework presents numerous complexities. Specifically, we encounter several challenges. It is essential to accurately integrate the mobile device's different sensors to ascertain the user's orientation and location. Moreover, there is a need for a robust and dependable method to compute the proximity between the user and POIs. Given the constrained resources and varying performance capacities of mobile devices, the spectrum of devices that can support such applications is quite narrow. Consequently,

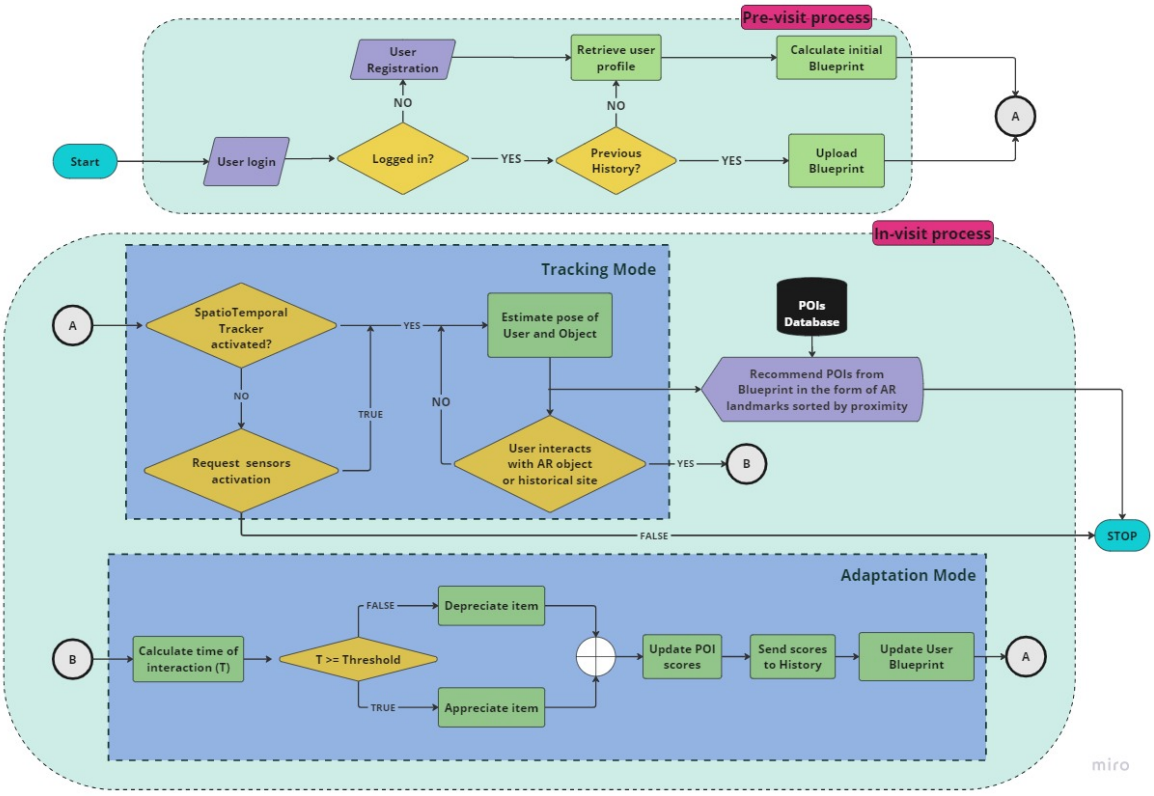


Fig. 4.6 Flowchart Depicting the Proposed Framework's Process Flow

ensuring consistent robustness and user-friendliness across diverse mobile operating systems is a non-trivial task (Geiger et al., 2014).

For developers aiming to integrate AR features into mobile applications, there exists an array of platforms and libraries —including Wikitude, Layar, Vuforia, and Kudan—that facilitate the effective utilization of visualization and geolocation components such as Cameras, GPS, compasses, accelerometers, etc. (Saxena, 2015).

Table 4.1 summarizes a comparative analysis and survey conducted on several prominent platforms. This survey aimed to identify a platform that offers comprehensive documentation, active forum support, and features conducive to the requirements of our project. Ultimately, WIKITUDE emerged as the platform of choice.

Table 4.1 Hierarchy of AR development tools from most complex to least complex (Billinghurst et al., 2015)

Type of tool	Skill required	Example
Low-level software, library, or framework	Strong programming skills	ARToolkit, osgART, MXRToolkit
Rapid prototyping tools	Some programming ability, design and prototyping skills.	FLARManager, OpenFrameworks, Wikitude.
Plug-in for existing developer tool	Skill with the developer tool that the plug-in works with	Vuforia, Metaio Unity plugins, AR-Media plug-ins.
Standalone AR authoring tools	No programming ability, can learn standalone tool	BuildAR, Wikitude Studio, Layar Creator, Metaio Creator.

4.3.2 FEZAR Functional Modeling

The development of FEZAR, a personalized location-based MAR system, involves a multi-stage modeling process to define and design the system's architecture and functionality. This process begins by transforming user expectations into system functionalities and tasks, which are visually represented through use case diagrams in section 4.3.2. However, to ensure a dynamic view of the application's behavior and to clearly illustrate interactions between humans and the machine or within the system itself, a more granular and detailed description is necessary, using activity diagrams in section 4.3.2 or flowcharts as depicted in Figure 4.6.

Requirement Analysis

As we began the process of building a user-centered prototype with FEZAR, the identification of needs and the structuring of user expectations were essential. To do this, we immersed ourselves in various discussion forums and consulted tourists' oriented mobile applications, to prepare them before they embark on their journey to tourist destinations.

Use Case Diagram

The use case diagram in Figure 4.7 provides an overview of the functional behavior of our application. Use cases are used to express the functional needs of tourists. There are three

actors: the user who can search, control and view POIs through the display device, the server which returns these POIs according to the camera orientation and the developer who manages the historical sites database and defines the functional architecture of the application.

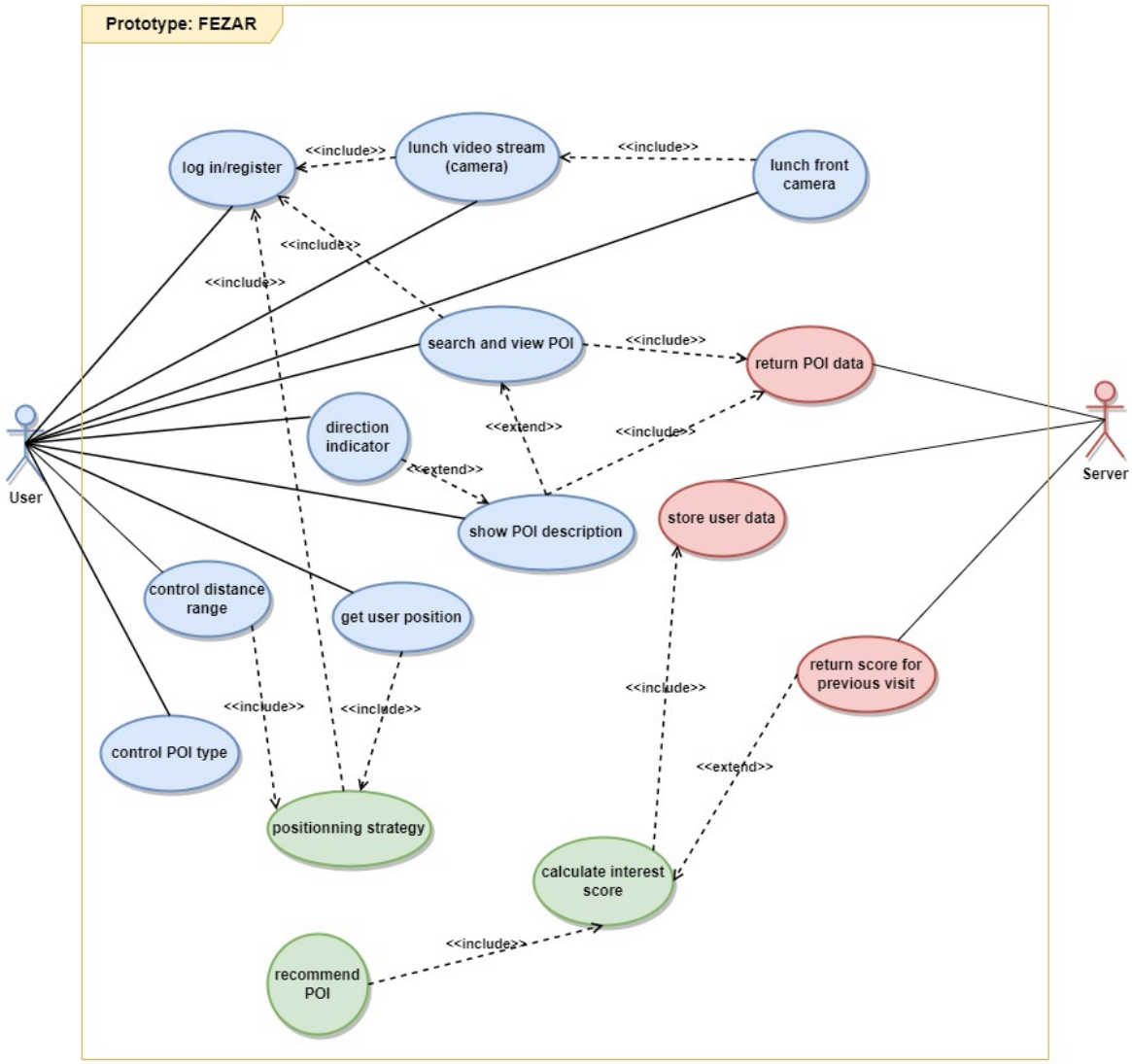


Fig. 4.7 Use case diagram of the prototype FEZAR

Activity Diagram

The application's dynamism is based on the user's interaction with its various features, which facilitates the activation of subsequent actions detailed in the activity diagram, as shown in figure 4.8. To take an example, when GPS is active and the camera is pointed at a historical site, the user receives an image marker symbolizing the monument. When this marker is selected, the user receives a detailed description and directions.

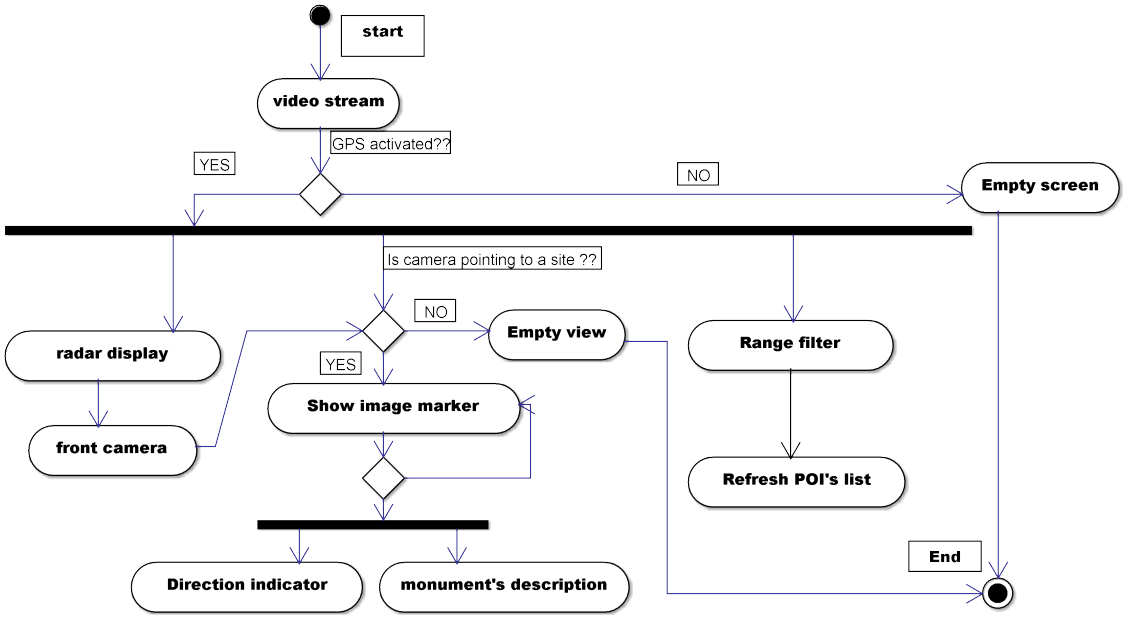


Fig. 4.8 Activity diagram of the prototype FEZAR

Data Modeling

In terms of data architecture and the relationships between different types of data, our database comprises a compilation of thirty-eight historical sites in the Medina of Fez. Each site is encapsulated in a JavaScript object and, collectively, these sites constitute an array of thirty-eight objects housed in a global variable. This structure makes it possible to retrieve information for each monument - including its title, type, description, coordinates and image - via a direct link to a JSON file hosted on a remote server, as illustrated in figure 4.9.

Development and Prototyping

The AR engine in our application prototype is powered by the Wikitude SDK (see Figure 4.9), designed specifically for the Android platform. Wikitude offers an advanced JavaScript API that simplifies the development of AR functionalities like scene recognition and GPS-based tracking through an intuitive markup language. Key AR functionalities of our prototype, as outlined below, are constructed using the Wikitude library. These features have been developed with a combination of HTML, JavaScript, CSS, and jQuery, alongside Java for native programming requirements.

- **Scene recognition**: The 'real' component (i.e. physical layer) of our AR system is captured through the mobile device's camera, which streams live video. Standard

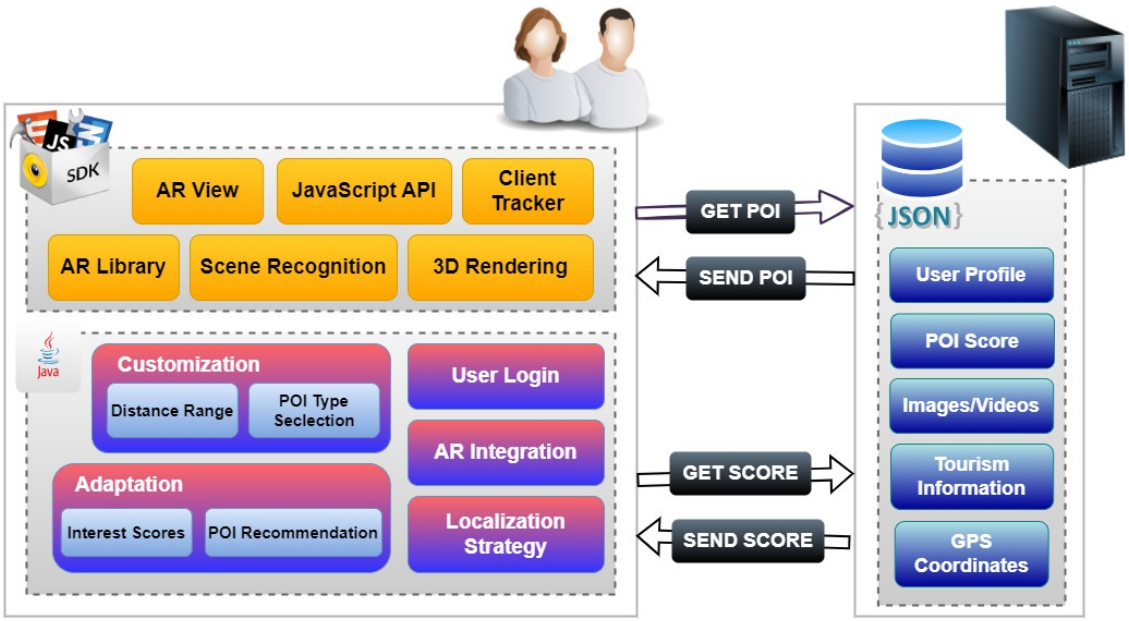


Fig. 4.9 Data architecture of the prototype FEZAR

built-in cameras alone are not equipped to detect the scene and render virtual objects, but the Wikitude API enhances this capability by providing scene recognition features. The sophistication of this functionality, however, depends on the type of licensing agreement in place with Wikitude.

- **POI rendering**: For the virtual layer of augmentation, when the application has successfully determined the user's precise location and orientation and retrieved the historical sites' data from the server through the tracking mode, the user can aim their device's camera at a monument to display the associated virtual marker as shown in Figure 4.10a. To create an interface that is both intuitive and engaging, we have assigned unique markers to each type of monument, details of which are presented in Table 4.2.

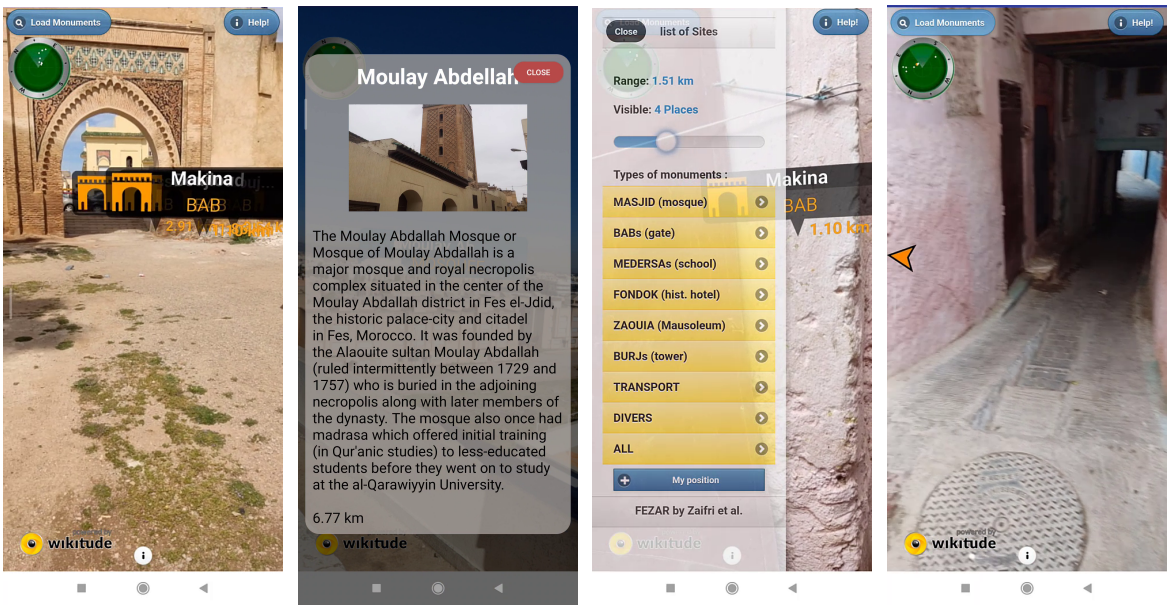
- **Geo-location and tracking**: Our framework employs a multi-sensor fusion strategy, using GPS, compass, accelerometer and gyroscope to determine the user's precise position and orientation in real time. This tracking mode is combined with a localization strategy that uses the exact coordinates of monuments to anchor them in physical space. When the user's location and orientation are in line with these coordinates, the system triggers contextual AR effects, seamlessly merging the virtual and real worlds in our application's interface (see Figure 4.5).

- **Customization modes**: Our MAR prototype enhances user interaction by offering two distinct Control Mode options: '***Distance Filtering***' in Figure 4.10c, allows users to set a specific radius within which monuments will be displayed, effectively creating a customized discovery zone; '***Sites Filtering*** in Figure 4.10c,' on the other hand, enables users to adjust the types of monuments they wish to explore.

- **Navigation Radar**: The radar feature empowers users to navigate in the application's global mode by providing a count of all available POIs within the user-selected diameter. Engaging the radar icon initiates a switch from the rear to the front camera, facilitating a seamless transition (see Figure 4.10d).

- **POI Description**: Upon the display of a POI's virtual marker on the device's screen, users can interact by selecting the marker to access an in-depth description of the historic site. These descriptions enrich the user's knowledge with historical context, provide the distance to the monument, offer a gallery of images for exploration, and include hyperlinks for additional information (see Figure 4.10b).

- **Directional indicator**: To enhance user orientation, our framework provides a solution for instances when a user selects a POI marker and then redirects their camera elsewhere, potentially losing track of the marker's position. To address this, we've integrated a directional indicator alongside each selected marker—a colored triangle that points towards the monument's direction—ensuring users can easily navigate towards their POI (see Figure 4.10d).



(a) Image markers of two POIs in front of a historic gate.

(b) Tourist information and images of a selected POI.

(c) Customization panel to adjust distance radius and POI types.

(d) Orientation symbol (Orange arrow) to a selected POI.

Fig. 4.10 Screen captures of the FEZAR prototype user interface.

Table 4.2 Visual markers for different types of POIs in the FEZAR system, illustrating distinct icons for selected and non-selected states.

Type of POI	Is selected	Is NOT selected
Masjid		
Medersas		
Gate		
Tower		
Logistics		
Mausoleum		
Hist. Hotel		
Divers		

4.4 Conclusion

This chapter has thoroughly described the design of FEZAR, a personalized, location-based AR framework designed to facilitate the autonomous guidance of tourists by proposing itineraries adapted to the tourist's profile and behavior during the visit. We further developed the key components of the FEZAR framework, leading to the development of the FEZAR prototype, a mobile AR tool for navigating open sites and enriching tourist experiences.

Currently, the prototype has been validated for use in the Medina of Fez, enabling tourists to discover and manage a list of historic sites within a customizable distance radius, and providing detailed descriptions for selected monuments. The scalability of the prototype for use in other cities has also been considered, assuming the POI database is updated.

The next chapter will deal with FEZAR's experimentation in the historic Medina of Fez, recognized as a UNESCO cultural heritage site and vibrant tourist center. We aim to validate and field-test FEZAR's effectiveness through expert laboratory evaluations and user assessments in the field, to compare user performance against conventional guidance tools. At the time of writing, we are actively developing the framework adaptation mode, with tracking and control modes already successfully implemented.

Chapter 5

Impact of mobile AR on User Performance

5.1 Introduction

Having detailed the design and implementation of FEZAR, a personalized AR model designed to improve tourists' navigation and way-finding experience in open cultural environments, this chapter will focus on subjecting FEZAR to empirical experimentation. The application will be compared with traditional navigation tools to conduct an empirical study of the effectiveness of FEZAR and a conventional 2D localization and navigation system (GMAP). The aim is to examine the impact of these systems on user performance during a tourist tour. Before user evaluation, we will conduct an expert usability assessment of FEZAR to confirm its usefulness and minimize usability problems.

After outlining empirical hypotheses in Section 5.2, the paper proceeds as follows: Section 5.3 describes the materials and methodology used for data collection. Section 5.4 details specific findings from both expert and user evaluations. The discussion in Section 5.5 covers the interpretation of results, confirmation of hypotheses, and suggestions for enhancements, leading up to the chapter's conclusion.

5.2 Empirical Hypotheses

Before initiating the empirical study, we established four empirical (operational) hypotheses derived from (RQ6) and (RQ7) as outlined in Section 1.3. These hypotheses are intended to guide the comparative study proceedings detailed in this chapter:

(H1): The use of the visual Mobile Augmented Reality (MAR) application is expected to make the visit more entertaining and enjoyable.

(H2): While the MAR application is anticipated to be more user-friendly compared to other navigational tools, it may also present more significant challenges in managing errors.

(H3): In the experimental setting using the MAR application, users will find it easier to orientate themselves towards historical points of interest.

(H4): The MAR application would facilitate access to tourist information for its users.

5.3 Materials and Methodology

This chapter focuses on evaluating the FEZAR augmented reality mobile application and a 2D digital navigation map (GMAP), aiming to assess user task performance and the influence of AR technology on tourist experiences. To achieve this, two primary evaluation methods are employed: heuristic evaluation for usability assessment, and user evaluation incorporating both subjective and objective metrics. This section begins with an overview of both devices, followed by detailed reports on usability tests conducted by experts at the University of Fez laboratory and field experiments carried out by representative users in the historic Medina of Fez. The research process and methodology are illustrated in Figure 5.1.

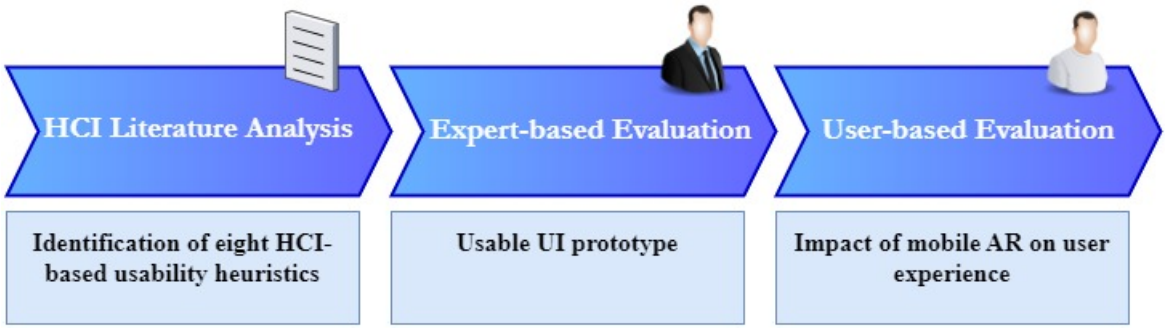


Fig. 5.1 Research workflow

5.3.1 Overview of FEZAR and GMAP systems

FEZAR, a mobile geo-based AR application, and GMAP, a 2D dig-ital geolocation map, are the two devices that are evaluated in this chapter as illustrated in Figure 5.2.

Geospatial-Enabled MAR Application: FEZAR

To examine and contrast user task performance across various experimental setups, we developed a mobile augmented reality (MAR) application named FEZAR, as detailed in Chapter 4. FEZAR is engineered to assess users' proximity to historical landmarks in the Fez Medina and to determine the orientation of their smartphone cameras. Additionally, it offers relevant information about these sites. The adaptability of the app is notable; by updating its database, which currently encompasses 38 key historical or logistical sites in the Fez Medina, FEZAR can be modified for use in other urban settings. We chose the Wikitude platform for development due to its advanced AR capabilities, including location-based 3D rendering, as shown in Figure 5.2b.

This chapter does not delve into the specifics of creating the application, as these details have been extensively covered in Chapter 4 and in (Zaifri et al., 2018). Instead, the emphasis here is solely on evaluating user performance. While the fundamental architecture of the application remained consistent, it's important to note that various improvements were made to the user interface design, along with additions and modifications to several features, following the usability test conducted by experts.

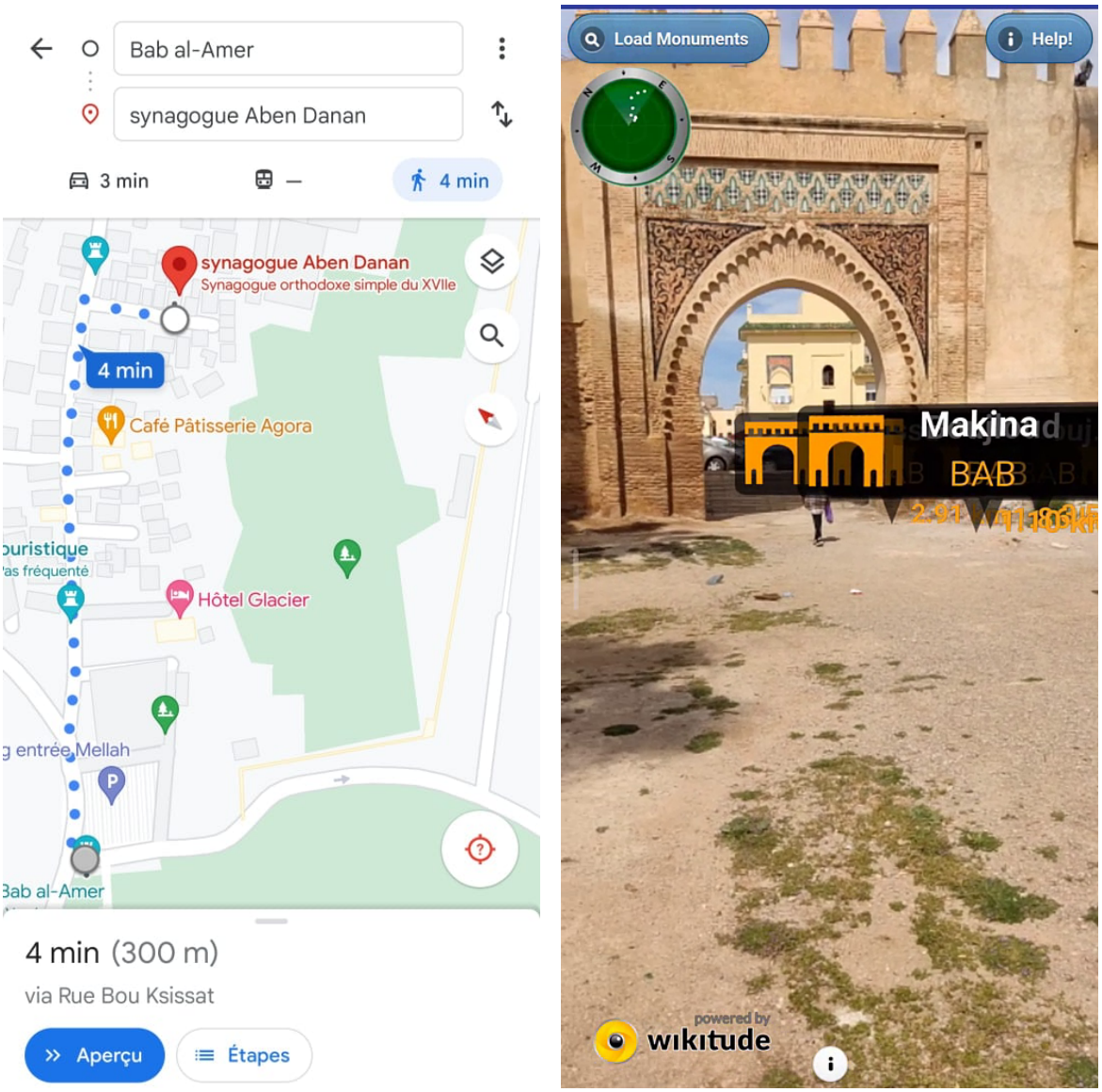
Two-Dimensional Mapping and Geolocation Tool: GMAP

A two-dimensional geolocation map, or digital map, is a type of mobile application or system that offers navigation and routing functionalities, along with detailed information about POIs. This information typically includes images, distances, descriptions, and hyperlinks. In our study, we aimed to compare the FEZAR application with a 2D geolocation map, focusing exclusively on 2D positioning features without incorporating any virtual 3D elements. For this comparison, any map meeting these criteria could be utilized. However, all participants in our experiments used the Google Maps Platform [1] as their chosen digital map (refer to Figure 5.2a).

5.3.2 In-Lab Usability Testing

The initial evaluation of interaction design based on user task analysis often involves heuristic evaluation, as noted by Bowman et al. (2002). The field of Human-Computer Interaction (HCI) is rich with various usability heuristics and design guidelines, as documented by researchers like Nielsen (2005), Dünser et al. (2007), Ko et al. (2013), Endsley et al. (2017), and Gabbard and Hix (2001).

[1] Google maps Platform: https://mapsplatform.google.com/intl/en/



(a) 2D navigation map view.

(b) Augmented reality application view.

Fig. 5.2 Captured Images of Both Evaluation Systems in Use

Dünser et al. (2007) defined eight HCI design principles specifically tailored for AR systems. While these principles provide a valuable foundation, they are presented as a preliminary guide and are open to further refinement. In our study, we expanded upon these rules to develop eight robust heuristics tailored for assessing the usability of location-based MAR interfaces, taking into account the unique characteristics and requirements of such systems.

1. **Affordance**:The application's design and interactive elements should intuitively convey its purpose to the user.

2. **Reducing mental strain**: The application must enable the user to concentrate on the main activity, using interaction methods that reduce the mental effort required to locate a selected point of interest (POI).

3. **Ease of use**: Users should be able to locate POIs through a few simple interactions. The application aims to eliminate needless actions, reducing fatigue and discomfort.

4. **Learnability**: The interface design should facilitate easy and effective learning for the user on how to use the app, with clear and intuitive graphical symbols.

5. **User satisfaction**: The app should captivate the user's interest in finding their desired POI and provide important information (like images, distance, and descriptions) to ease the search process.

6. **Flexibility in use**: The app should offer options for users to customize the navigation distance and the types of POIs displayed, supporting various interaction modes.

7. **Responsiveness & feedback**: The application should offer timely feedback to users, making them aware of the system's current state and the immediate impact of their actions in the virtual environment.

8. **Error Management**: While the application should be designed to avert errors, it must also alert users to errors and provide solutions or recovery options when necessary.

Experiment protocol

Following the recommendations of Nielsen and Molich (1990), who recommend using three to five evaluators for this kind of assessment, we selected five experts with strong expertise in computer vision, mobile user interfaces, and augmented reality. The group consisted of four males and one female, with their ages ranging between 25 and 30 years.

As outlined in Appendix A, we assigned nine specific tasks to the five evaluators for completion using the FEZAR application. This exercise was aimed at facilitating a thorough examination of the user interface and the identification of any usability problems. Subsequently, the evaluators were tasked with determining which of the eight heuristic principles were violated by the identified usability issues.

The evaluation sessions were conducted at the Faculty of Science Dhar El Mahraz in Fez, utilizing both the informatics laboratory and various public spaces to allow evaluators the

freedom to move around as needed. Prior to beginning the tests, we encouraged testers to familiarize themselves with the application's interface independently, ensuring they were comfortable with the system's functionality. Following Nielsen's methodology (Nielsen, 1994a), each identified usability issue was assigned a severity rating ranging from 1 to 5. This scale prioritizes the most critical problems, suggesting that high-priority issues either be rectified or approached differently. In addition to identifying usability issues, evaluators were also tasked with proposing enhancements for each task, as detailed in Table 5.4.

5.3.3 On-Site Field Evaluation

User experience Questionnaire

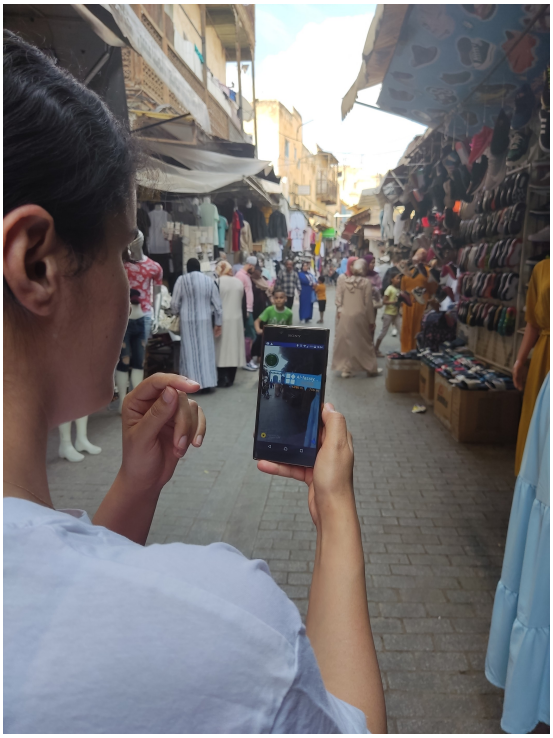
Wever (2003) distinguishes four main categories to collect the primary data from representative users: interviews, questionnaires, observation, and product analysis. The primary data varies depending on the user's preferences, opinions, rankings, and comments.

Because data comparability is more assured with written questions (van Elzakker et al., 2008) and because questionnaires are more cost-effective than video/audio recording or observation, which requires following each group of users, questionnaires are frequently more convenient and consistent than personal interviews (Bowman et al., 2002). Written questionnaires were used in previous studies to analyze a variety of user experience parameters in the augmented reality context, including measuring users' immersion in location-based AR environments (Georgiou and Kyza, 2017), task performance of users while testing AR prototypes (Chen, 2014), and the usability of AR systems (Nilsson and Johansson, 2008). The calculation of presence scores in augmented environments (Schuemie et al., 2001) and the comparison of presence scores in real and virtual spaces (Usoh et al., 2000) can both be done successfully using questionnaires. In light of these findings, the methodology for this comparative study's hypothesis testing is a quantitative survey.

Nevertheless, questionnaires have a number of limitations since participants may be led in the direction of the researchers' predictions (van Elzakker et al., 2008) and the quality of the data is largely dependent on the subject's effort and cooperation (Chua et al., 2016). Combining subjective and objective approaches will overcome this constraint. Data recording will give us quantitative information about, for instance, how many users arrived at the right locations or how long it takes a user to complete a task (see Table 5.3).

Experiment participants

Table 5.1 illustrates the sample characteristics of the two groups that toke part in the experiment. We randomly chose 40 sample users for user testing, 24 men and 16 women. With



(a)



(b)



(c)



(d)

Fig. 5.3 Users from group B operating the FEZAR application in various scenarios in the Mellah Alley during the experiment.

Table 5.1 Comparison of Characteristics between FEZAR and GMAP Users

Characteristic	Value	FEZAR	GMAP
		Frequency	Frequency
Gender	Male	11 (55%)	13 (65%)
	Female	9 (45%)	7 (35%)
Age	18-24	2 (10%)	11 (55%)
	25-34	17 (85%)	6 (30%)
	35-40	1 (5%)	3 (15%)
Previous experience with AR	Yes	6 (30%)	2 (10%)
	No	10 (50%)	12 (60%)
	No knowledge of AR	4 (20%)	6 (30%)
Previous visit to the test area	Yes	6 (30%)	11 (55%)
	No	14 (70%)	9 (45%)
Occupation	Teacher	8 (40%)	3 (15%)
	Student	5 (25%)	14 (70%)
	Engineer	2 (10%)	0 (0%)
	Technician	2 (10%)	0 (0%)
	State employee	2 (10%)	1 (5%)
	No job	1 (5%)	1 (5%)
	N/A	0 (0%)	1 (5%)

a mean age of 26.82 and a variance of 4.97, they ranged in age from 18 to 40. We used an online survey with questions about users' prior experience with AR applications and their level of tourist orientation to make sure that these users were not experts. In total, 20% of the users had experience with AR applications, 55% had never used one but had a basic grasp of it, and 25% had no idea what an AR application was. We split the participants into two equal groups, an experimental group for the AR prototype and a control group for the geo-location map, using a randomized approach. It is important to highlight that sample members' ability to recognize or access some test monuments without the use of assistive technology was not taken into account by the sample selection procedures.

Experiment scenario

Both tourists and handcraft vendors frequent the selected circuit. The Mellah neighborhood is made up of roughly seven ancient monuments and is a 500-meter passageway between two

gates. Participants from both groups were invited individually, and we thoroughly laid out the entire procedure. The users were required to use a smartphone that we have provided to complete the same scenario-based tasks, specifically exploring five landmarks in the Mellah alley as shown in Figure 5.4. Before arriving at the target (Semmarine gate), each user set out from a starting point (El Amer gate) and sought to see three landmarks along the road (Aben-Danan synagogue, Fassiyine synagogue, and Magana gate). Users completed a questionnaire after finishing the circuit and the activities. The neighborhood itself is a historical landmark and is frequently congested, making it a suitable location to test how well our geo-based augmented reality prototype would perform in a crowded situation (see Figure 5.3).



Fig. 5.4 Chosen Route for the Research Project

Questionnaire measures

A preliminary observation is that there is a lack of research studies in this area to utilize a unified ready-to-use model, thus researchers must make an independent effort to develop specific questionnaires tailored to the case under investigation (Vlachoudi et al., 2023). Having said that, the literature review stage was followed by a team discussion to determine and redefine the dependent variables for this comparative study as shown in Table 5.3. There were additional team discussions after the experiment's variables were determined with the aim of converting the four dependent variables into distinct formal questions that would make up the body of the questionnaire, which would allow us to test the theoretical hypotheses.

As shown in Appendix B, the questionnaire was broken down into five sections, with the first four allowing users to evaluate the four dependent variables and a fifth of which was reserved for concluding overarching thoughts and suggestions. Since the majority of the questions are closed-ended, we decided to utilize a 4-point Likert scale to prevent misunderstanding caused by neutral responses. To enable people to voice their opinions or comments, we added some open-ended questions. Direct, conditional, and dichotomous questions are also available.

Experiment variables and metrics

Bowman et al. argued in (Bowman et al., 2002) that, in the context of virtual environments (VEs), duration of visit and precision are two important quantitative metrics, in addition to various subjective performance values, such as user comfort, perceived ease of use, and ease of learning. Since the device used in this experiment serves as the independent variable, the device used by the experimental group was FEZAR, and the device used by the control group was GMAP. Independent variables of the comparative study are shown in Table 5.2.

Table 5.2 The independent variables of the study

Test sample	Independent variable	Abbrev.	(N=)
Experimental group	Geo-based augmented reality prototype	FEZAR	20
Control group	2D geolocation map	GMAP	20

Table 5.3 The dependent variables under study.

Dependent variable	Definition
Usability	The ability of a product to be used by users to achieve specific goals (Sutherland, 1968).
Informativeness	Give an overview of the current POI; it includes a brief description, distance, helpful links, address and contact information (Pospischil et al., 2002).
Enjoyment	The content must amuse the visitor and make the experience more pleasant and interesting (Kaghat et al., 2020).
POI localization	The possibility to obtain directions and navigation to a POI once it is visualized in AR view and selected (Umlauft et al., 2003).
Duration of visit	The time required to perform the task.
Precision	The number of errors incurred during the execution of tasks.

As described in Table 5.3, the dependent variables are usability, POI localization, informativeness, enjoyment, Duration of visit, and precision. The logging method was used to capture, in real time, the traces of the visit. From these logs, we were able to know the number of errors made by the visitor during his visit, as well as the time spent.

5.4 Results and Data Analysis

For data collection, our approach included two distinct evaluation methods: a heuristic evaluation for assessing usability, and a user evaluation incorporating both subjective and objective metrics. Initially, we present findings from the expert evaluations, followed by insights from user responses obtained via questionnaires and the logging method.

5.4.1 Heuristic Evaluation

Table 5.4 outlines the findings from the heuristic evaluation. This table describes, for each task, the issues identified by the evaluators (E1 to E5), the specific heuristic principle each issue violated, its severity rating, and any comments or proposed solutions offered by the evaluators for each identified issue. Through this heuristic evaluation, we pinpointed 20 usability issues, averaging a severity rate of 3.5. We successfully resolved 80% of these issues, with the unsolved problems primarily related to device compatibility issues with the AR API. We prioritized addressing issues with a severity rating above two (Zaifri et al., 2023b).

The most commonly encountered issues during the evaluation were related to reducing mental strain and enhancing the application's flexibility. The experts noted that the prototype's inability to update distances to certain locations in real time necessitated additional cognitive effort from users to understand its operation, load monument data, and interact with the AR layer represented by floating symbols. The app calculates the real-time distance to POIs using the GPS system. However, the accuracy of GPS, or its complete failure, is significantly affected by the narrow alleys of the medieval Medina. Despite the increased demand on mobile device resources, the use of a hybrid location system, combining GPS, WIFI, and GSM, is deemed essential for improved functionality (Zaifri et al., 2023b).

AR mobile applications stand apart from traditional mobile or desktop applications in their interaction methods and interface design. The AR icons, overlaid on the physical environment of historical sites and not fixed to the screen, created confusion among users, making it challenging for them to notice if they had arrived at a POI or to ascertain their current location. A suggested solution is to display a notification when users are near their

Table 5.4 Heuristic evaluation findings.

Task	Evaluator	Problems encountered	Heuristic(s) violated	Severity	Suggestions.
1	E1	The notification asking me to enable GPS was not visible to me. I reopened the application, chose Help to learn the cause, and then turned on GPS. I had to click Load Monuments to display their locations on the screen after waiting until I realized this.	Learnability.	4	I suggest adding a prompt window in place of the small message that appears briefly and then disappears. Alternatively, you can lengthen the delay so that it appears continuously until the user enables the GPS, or you can have a message appear when the user clicks Load Monuments informing him that he must enable the GPS. Additionally, I recommend auto-loading the monuments in the app.
	E2	When I used the app on my Samsung Galaxy Tab 3, I ran into a situation where the map and monuments were both fixed and did not move, even when I moved. But on other devices, the app operated without a problem.	Affordance	3	The app should operate across a variety of platforms and devices in order to ensure maximum usability.
	E3		Reducing mental strain	1	The monuments should load automatically when the GPS is activated.

Continued on next page

Table 5.4 continued from previous page

Task	Evaluator	Problems encountered	Heuristic(s) violated	Severity	Suggestions or comments
2	E1	I tried clicking anywhere to close the image after clicking to view it to see if that would shut it, but it didn't, so I just clicked return to dismiss the image.	Reducing mental strain.	3	Add a "close icon" to close the image or a "click anywhere" function to close.
	E2	No problem has been encountered.	User satisfaction.	1	If visitors to Fez are lost in the narrow lanes of the old town of Medina, I think it will be difficult for them to find the monuments because the map doesn't give enough information.
	E4	The description panel of Jnan Sbil don't scroll down and the distance disappeared.	User satisfaction.	3	Add scroll function.
3	E1	Yes, I can easily locate my destination but finding my position is challenging because the application only gives me a coordinate number that gives no indication of where I am.	Responsiveness and feedback.	2	When I clicked "My position," a map pop-up showing people's places in relation to monuments should have appeared.
	E3	Latitude and longitude by themselves are useless; the location must be shown on a map or have instructions.	Responsiveness and feedback.	3	
	E5	It was hard to find it. Did not receive coordinates inside the building.	Reducing mental strain.	1	Add the button to locate user on first activity.

Continued on next page

Table 5.4 continued from previous page

Task	Evaluator	Problems encountered	Heuristic(s) violated	Severity	Suggestions or comments
4	E4	There are 6 places in mosque category but I only found 5.	Ease of use.	2	The radar shows 6 dots.
6	E4	No update for the distance.	Flexibility in use.	4	Show distance on markers.
	E5	I missed the update for two minutes.	Flexibility in use.	3	Add distance to 3D markers.
7	E4	I Did not find the distance controller easily.	Flexibility in use.	1	
	E5		Flexibility in use.	1	Distance bar should start with minimum value, and not include the percentage values, otherwise, it would be confusing.
8	E5		Ease of use	1	It would be helpful if the list disappears after clicking a type.
9	E1	The GPS warning message is small to be seen by all users.	Learnability	4	I suggest making a prompt window instead of a small message.
	E2		Error Management	1	The app quickly (3 or 4 seconds) asks the user to enable GPS before asking them to restart it. In my opinion, the message should be displayed as long as the app is running (when the GPS is not activated).

destination. Additionally, one expert proposed integrating a feature to show a map indicating the user's current location. For the app to be user-friendly, the AR icons must be intuitive, and the app's functionality should facilitate easy adoption for the user (Zaifri et al., 2023b).

Feedback from expert evaluators proved invaluable in enhancing the system's usability. The prototype was well-received overall, with experts appreciating the innovative use of AR to provide precise geolocation and historical information by simply pointing a camera at a historical site (Zaifri et al., 2023b).

5.4.2 User Evaluation

Upon finishing their visit, participants were requested to fill out a questionnaire. This questionnaire comprised 26 questions for those who used the FEZAR application and 20 questions for the GMAP group. Out of these, 15 questions in each set were specifically related to the experiment, as detailed in Figure 5.5. The additional questions were designed to collect user feedback and suggestions regarding their visit, which will be instrumental for future enhancements. The complete questionnaires for both the FEZAR and GMAP groups, used in this empirical study, are thoroughly depicted in Appendices A and B.

ANOVA for Data Analysis

To evaluate the significance of our findings and the impact of participants' gender and familiarity with AR on the results, we employed an Analysis of Variance (ANOVA) test.

We assessed two key metrics for each participant in both the FEZAR and GMAP systems: the duration of the visit and the number of POIs missed. When comparing the visit durations between the FEZAR and GMAP systems, we observed that the variance was not statistically significant ($F = 1.110$, $P = 0.299$). However, a significant difference was noted in the number of missed POIs between the two experimental setups ($F = 7.435$, $P = 0.010$), indicating a notable disparity in performance between the two systems regarding the participants' ability to locate POIs.

In the subsequent phase of our study, we examined the impact of participants' gender and their familiarity with AR on the results. We categorized participants within each system (FEZAR and GMAP) based on gender, forming male and female groups.

For the FEZAR system, the analysis showed a significant difference between male and female participants in terms of both visit duration ($F = 157.920$, $P < 0.001$) and the number of missed POIs ($F = 25.6$, $P < 0.001$). This indicates a distinct variance in how each gender interacted with and navigated the FEZAR system. Conversely, within the GMAP system, while the difference in visit duration between genders was significant ($F = 149.001$, $P <$

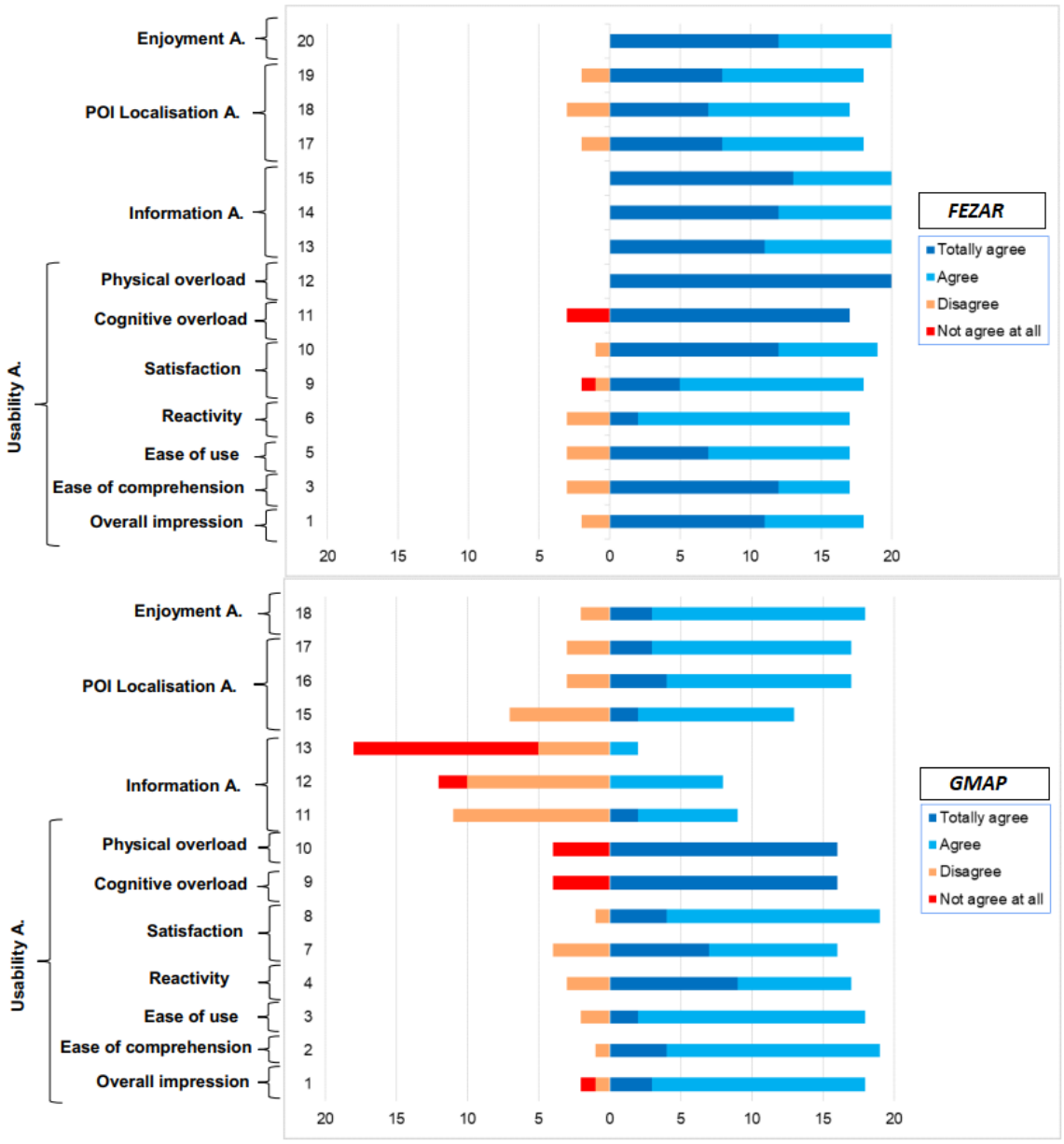


Fig. 5.5 Comparative Questionnaire Findings for FEZAR (Top) and GMAP (Bottom)

0.001), the variance in the number of missed POIs was not statistically significant ($F = 2.295$, $P = 0.138$). This suggests that gender had a notable impact on the time spent navigating with GMAP, but not necessarily on the effectiveness of locating POIs.

To assess the influence of user familiarity with AR, participants were divided into three categories: those who had prior experience using an AR application, those who know AR concept but had never used an AR application, and those unfamiliar with what AR is.

In the case of the FEZAR system, significant differences were observed among these groups both in terms of visit duration ($F = 137.672$, $P < 0.001$) and the number of missed POIs ($F = 41.376$, $P < 0.001$). This indicates that prior experience with AR significantly affected how participants interacted with the FEZAR application. Similarly, for the GMAP system, significant differences were found in both the visit duration ($F = 252.134$, $P < 0.001$) and the number of missed POIs ($F = 35.369$, $P < 0.001$). The remarkable variance of these results can be attributed to an unbalanced distribution of participants between these three groups. Notably, 55% of participants had never used an AR application prior to this test, which may have influenced their performance with both FEZAR and GMAP systems.

Descriptive Analysis of the Questionnaire Data

The results from the user evaluation, depicted in Figure 5.5 and Table 5.5, effectively highlight the level of user satisfaction with the FEZAR application. To delve deeper into these findings, a comparative analysis between the FEZAR app and GMAP was conducted, focusing on six key dependent variables (Zaifri et al., 2023b).

- **Duration of visit**: As shown in Figure 5.6, users of the FEZAR application spent an average of 22 minutes and 36 seconds (±1 minute and 16 seconds), as indicated by the 95% confidence interval. Comparatively, the average time spent by GMAP users was

Table 5.5 Comparison of Mean and Standard Deviation for Dependent Variables in the FEZAR and GMAP Groups

Dependent variables	FEZAR		GMAP	
	Mean	S.D.	Mean	S.D.
Usability	2.40625	≈0.7441	≈2.194	≈0.802
Information	2.6	≈0.4899	1.1	≈0.8103
Navigation	2.267	≈0.6549	≈1.933	≈0.6018
Enjoyment	2.6	≈0.4609	2.05	≈0.4738
Duration of visit (h:m:s)	0:22:36	≈0:05:32	0:20:30	≈0:06:42
Precision	0.975	≈0.713	1.85	≈1.301

slightly less, at 20 minutes and 30 seconds (±1 minute and 32 seconds), also within a 95% confidence interval. This suggests that users of FEZAR tend to spend additional time exploring the monuments on the way to their final destination.

- **Precision**: As depicted in Figure 5.7, a mere 35% of users utilizing FEZAR successfully visited all designated POIs, while the remaining 65% overlooked between one and three monuments during their visit. In contrast, a smaller proportion, only 10%, of GMAP users managed to find all five POIs. A significant 70% missed one to three monuments, and 20% failed to locate three to five monuments. From these statistics, it's evident that FEZAR users generally explored a greater number of monuments compared to those using GMAP during their tours.

- **Usability**: The evaluation of each system's usability encompassed factors such as user satisfaction, system responsiveness, cognitive and physical demand, ease of use and understanding, along with the general user impression. As summarized in Figure 5.5, these usability parameters distinctly show that FEZAR is highly regarded for its user-friendliness and ease of use, imposing minimal mental or physical strain on its users.

- **Localization of POIs**: FEZAR users reported a slightly higher ease of navigation and guidance around landmarks during their tour compared to GMAP users, with 87.5% of FEZAR users finding it straightforward versus 85% of GMAP users. Furthermore, a significantly larger proportion of FEZAR users (90%) experienced ease in locating the final destination, in contrast to 65% of those using GMAP.

- **Information**: This aspect focused on evaluating each system's capability in providing users with accessible and comprehensive information about historical sites. Key factors included the ease of accessing tourist information and the quality of monument descriptions during visits. According to Figure 5.5, FEZAR outperformed GMAP in terms of informativeness. All FEZAR users (100%) reported that the application facilitated direct and swift access to tourist information, also providing sufficient descriptions for each location visited. In contrast, only 10% of GMAP users could directly access tourist information from the POIs, and about 40% found the information provided by the system's interface to be sufficient for the monuments.

- **User Enjoyment**: The level of enjoyment experienced by users was a key metric in assessing both systems. All users who interacted with FEZAR (100%) reported enjoying their tour, with a significant 60% rating their experience as highly enjoyable. In contrast, GMAP user responses were more mixed: 10% described their visit as

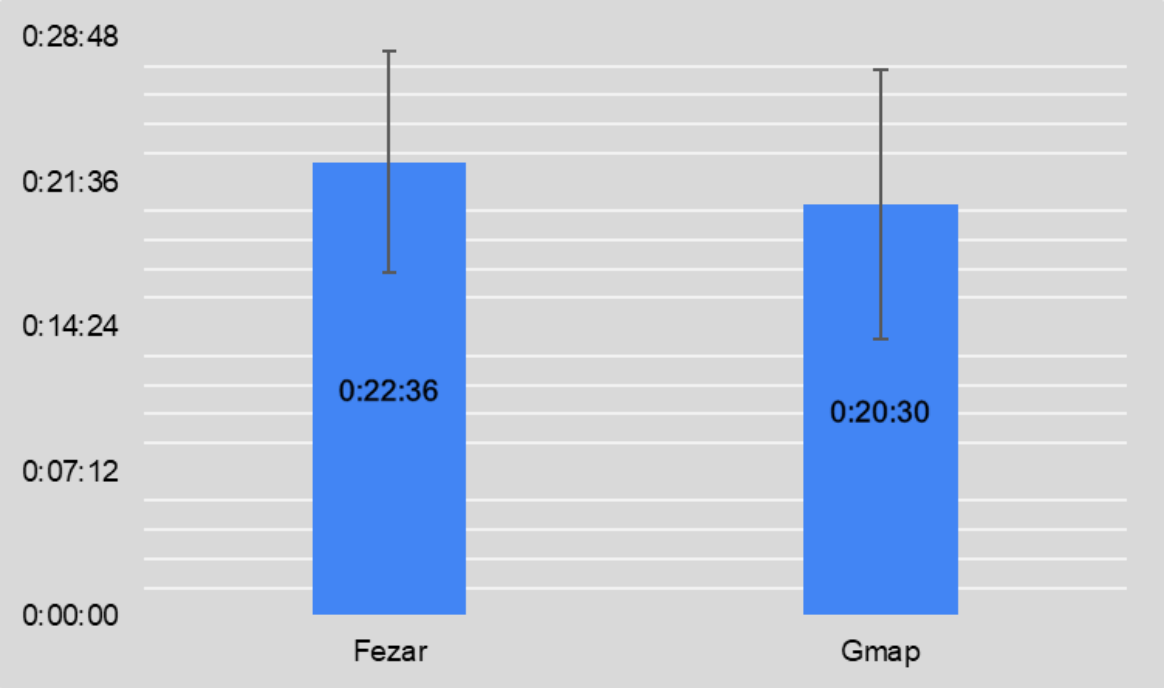


Fig. 5.6 Comparison of Average Visit Duration for Each Device (95% Confidence Interval)

somewhat uninteresting, 75% found it to be amusing, and 15% rated their experience as very amusing.

5.5 Discussion

The findings from the objective measurements reveal that users of FEZAR tend to spend more time locating points of interest compared to those using GMAP. This increased duration can likely be attributed to FEZAR's design, which encourages users to approach the monuments more closely and engage in comparing the images provided in the app with their real-world correspondents. Additionally, the data indicates that FEZAR users successfully located and explored a greater number of monuments than GMAP users, a factor that contributes to the extended duration of their visits. These results support the hypotheses we initially proposed prior to conducting the user evaluation, as they align with both the objective and subjective outcomes observed in our study:

Hypothesis H1: The responses from the questionnaire strongly suggest that participants enjoyed their experience more with FEZAR compared to other methods. This supports the validation of Hypothesis H1, which relates to the aspect of enjoyment. One possible reason for this higher level of enjoyment among FEZAR users could be their novelty in using the AR

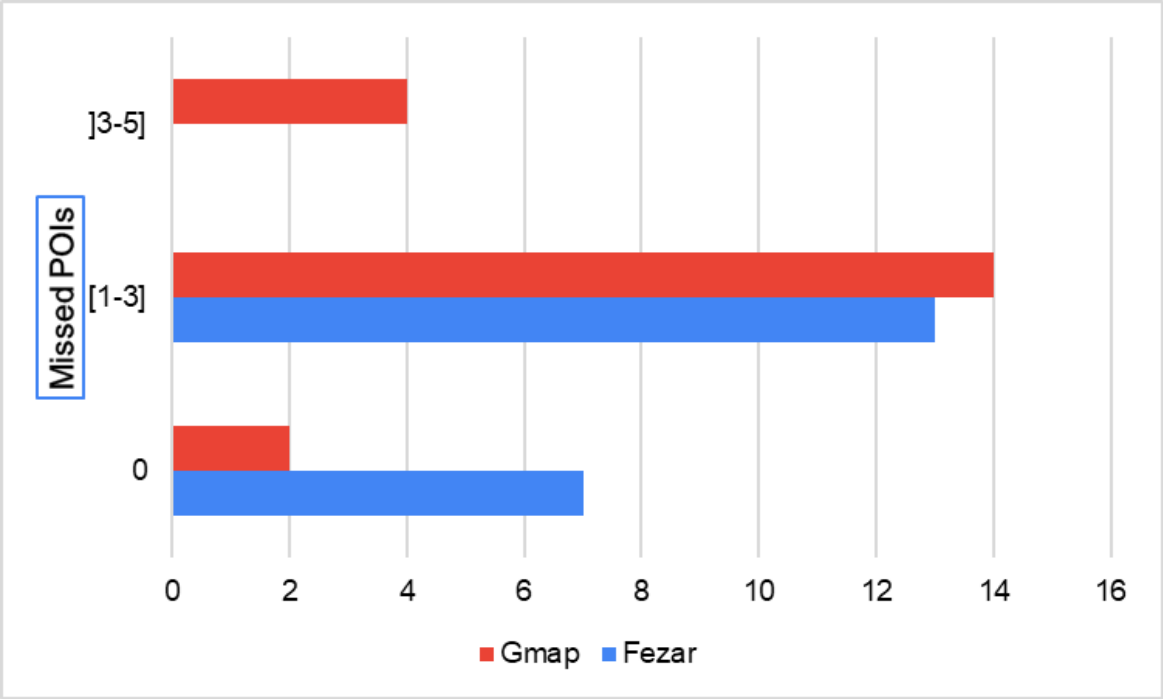


Fig. 5.7 Number of Overlooked POIs in Each Evaluated System

application. The majority of these users were excited by the prospect of receiving real-time guidance, instructions, and detailed information about monuments, complete with images, simply by pointing their camera in a particular direction. A significant 90% of FEZAR users expressed their willingness to download the latest version of the app for future visits to Fez, further underscoring their positive experience.

Hypothesis H2: The data gathered implies that FEZAR was highly regarded for its usability by the participants who tested the application. This suggests that the usability test, conducted prior to the user evaluation, played a crucial role in upgrading FEZAR into a user-friendly application. As highlighted by Tan et al. (2009), implementing heuristic analysis at the early stages, before user evaluation, tends to identify a wider range of problems with various severity levels more effectively than user evaluations alone. However, our study did not yield definitive evidence to assert that the AR application, FEZAR, is categorically more user-friendly than other navigational tools used for guidance. Additionally, the correlation between the number of monuments missed and the high usability of the system was not found to be significant. Therefore, based on these observations, it appears that the results do not support the validation of Hypothesis H2. The lack of a clear distinction in usability between FEZAR and other methods suggests the need for further investigation or refinement.

Hypothesis H3: The findings indicate that FEZAR does enhance navigation and guidance during the tour, particularly in terms of locating POIs. However, the evidence gathered was

insufficient to determine that users found it easier to navigate to monuments using the AR application as opposed to other methods. Therefore, Hypothesis H3, which posited that FEZAR would simplify the process of navigating to monuments, cannot be confirmed based on the current data. A potential reason for this outcome could be related to the design of the FEZAR application, which does not impose specific navigational routes on the user. This aspect of the design might have contributed to the users' perception of navigation difficulty. Feedback from several participants indicated a desire for an added feature in the application: an AR-assisted itinerary for each POI. Incorporating this feature might enhance the ease of navigation and could be a valuable consideration for future iterations of the application.

Hypothesis H4: The results derived from the questionnaire clearly indicate that FEZAR is perceived as being more informative than GMAP, marked by a significant difference. This aligns with the observation that FEZAR users spend more time reading descriptions at heritage sites, supporting the validation of Hypothesis H4. The interaction methods employed in FEZAR, such as location-based and distance-based filtering, along with the use of universally recognized icons and type-based AR markers, effectively reduce information "noise." This approach facilitates users' direct access to pertinent information about the tourist attractions they visit.

Our findings are in line with earlier research in the field of augmented reality (AR) for enhancing tourist experiences. For instance, Kaghat et al.'s study (Kaghat et al., 2020) on the SARIM audio AR model showed improved visitor experiences in museums, making them more informative and enjoyable compared to traditional guides. Similarly, Kourouthanassis et al. (Kourouthanassis et al., 2015) found that their AR app, CorfuAR, elicited positive emotions during visits. Additionally, Phithak et al.'s usability test (Phithak and Kamollimsakul, 2020) on the KORAT AR application demonstrated a high usability score, underscoring the potential of AR in tourism.

Our empirical study has faced certain limitations including reliance on self-reported data via questionnaires, which are subjective. Further depth could be achieved with qualitative methods like interviews. Our key performance metrics — visit duration and navigation precision — were measured using logging methods due to development constraints, highlighting the need for automatic data collection for reliability. Additionally, the sample size was limited to 40 users instead of the planned 100, due to time and funding constraints, affecting the generalizability of our findings. More representative results could be obtained with a larger, more diverse group of actual tourists.

5.6 Conclusion

This chapter details a comparative field study focusing on user task performance using the location-based AR mobile app, FEZAR. Initially, five experts carried out a heuristic evaluation, identifying and addressing various usability issues within FEZAR. They collectively recognized the potential of the application, although acknowledging its need for further development. Subsequently, forty representative users participated in a user evaluation, navigating through the narrow streets of Fes Medina and visiting five historical sites. The study compared FEZAR with GMAP, measuring parameters such as duration of the visit, navigation precision, tool usability, POI localization, informativeness, and overall enjoyment experienced by users.

According to the results, FEZAR is a very usable medium that makes it easy to locate monuments while increasing the visitor's interest in them. FEZAR made the visit much more pleasant and facilitated access to sufficient tourist information, compared to other mediums used. We believe that there is good evidence that MAR technology positively affects the user experience in the context of crowded tourist destination.

Chapter 6

Conclusion

In this thesis, our objective was to address the challenges of location-based visual augmented reality (AR) for tourism navigation and guidance in open cultural heritage sites. We proposed a conceptual framework and subsequently developed a mobile solution called FEZAR, that leverages visual AR to help tourists navigate and learn about historical sites. This chapter summarizes the main findings of our research and highlights theoretical and practical contributions and implications. In addition, it outlines the way forward for ongoing improvements and the potential extension of our results to new fields.

6.1 Summary and Contributions

The research approach adopted in this thesis follows recognized human-computer interaction (HCI) protocols. A comprehensive literature review was carried out to gather current knowledge on AR technology in the tourism sector and identify research gaps. Subsequently, we developed a proof-of-concept prototype of location-based mobile visual AR, specifically designed to answer the research questions posed, in particular, whether such AR solutions could serve as a basis for self-guided tourism in the near future. This prototype laid the foundations for the experimental phase, during which data was systematically collected through empirical research and closely examined, confirming or refuting the proposed research hypotheses and investigating user adoption of AR in a crowded tourist destination.

Within this thesis, we pinpointed three main areas where research was lacking: concepts (*Conceptual gap*), practical experience (*Empirical gap*), and geographical coverage (*Geographical gap*). By addressing these gaps, we believe we have contributed valuable insights to the academic debate in our field.

Addressing the conceptual gap identified, we have introduced FEZAR, a personalized and location-based AR framework. FEZAR aims to provide tourists with personalized

navigational assistance in open-air settings through the application of location-based AR. It utilizes a combination of the user's demographic data and spatial-temporal context, as well as behavioral data gathered from interactions with POIs, to calculate and continually update interest scores. This process allows for dynamic, real-time recommendations of POIs, presented as virtual landmarks. The interest scores evolve in response to the user's profile and their engagement with the historical sites or related AR objects, ensuring a personalized and contextually relevant experience.

FEZAR shapes the tourist experience by integrating three central models. First, the Visit Model that encompasses the physical (historic sites), virtual (virtual landmarks), and semantic (thesaurus tags) dimensions of a user's visit. Second, the Visitor Model, dedicated to capturing and storing user profiles and behavioral data to understand their preferences and interests. Finally, the Interaction Model orchestrates the dynamic relationship between the visitor's data and the visit's layers via three modes: Tracking, Control, and Adaptation. We are confident that FEZAR can foster deeper engagement and improve decision-making and planning for navigation through personalized recommendations. However, we must also consider the limitations, such as the need to protect user privacy and the influence of shared tags on the system's adaptability.

We have progressed in implementing the essential elements of the FEZAR framework, leading to the production of the FEZAR prototype. This mobile AR tool is conceived for navigation in outdoor environments and aims to enhance the experience of tourists visiting the historic Medina of Fez. The FEZAR prototype tracks the user and displays virtual landmarks aligned with the user's camera pose. It offers a customized experience, allowing users to control and select their preferred types of landmarks and the distance at which they should appear. Furthermore, when the user is interested in a POI, they receive a full description and basic directional compass.

Regarding the empirical gap, we field-tested the FEZAR prototype within the crowded environment of Fez's historic Medina through an extensive empirical study. Our goal was to evaluate how well users performed tasks using FEZAR compared to traditional navigation tools, examining the influence of MAR technology on UX aspects such as navigation, enjoyment, and information accessibility in densely visited tourist locales. In doing so, we aimed to address the empirical gap raised by limited research into the various UX facets when evaluating AR technologies. Before the main user study, five experts performed a heuristic evaluation of FEZAR to ensure its usability. Their feedback was instrumental in identifying and addressing any usability concerns with our location-based AR prototype.

Subsequently, forty participants evaluated the system in the narrow passageways of Fez's old Medina. This evaluation compared FEZAR, used by twenty individuals in the

experimental group, against GMAP, a conventional navigation app used by another twenty in the control group. The study utilized objective measures such as task completion time and locations missed, alongside subjective assessments from questionnaires that measured four UX dimensions: usability, POI localization, informativeness, and enjoyment. The results indicated that FEZAR is a highly usable platform that not only makes it easier to discover POIs but also significantly boosts engagement with them. Additionally, the findings suggest that FEZAR enhances the overall enjoyment of the visit and provides easier access to tourist information than other methods. However, the study also had its limitations, including a restricted sample size, limited generalizability of results, and a need for more automated methods of objective data collection.

Our empirical study of FEZAR in the Medina of Fez has also addressed a geographical gap in tourism AR research. The Medina, located in a less frequently explored North African context, enriches the corpus of location-based AR studies thanks to its unique cultural and historical significance. The inclusion of this region broadens the geographical diversity of AR research, which has traditionally focused on Europe, Asia, and North America.

6.2 Implications

Theoretical and practical implications can be drawn from our thesis, to initiate new research and discussions on tourism and AR at the academic and industrial levels.

In theory, this work is a basic resource for AR and tourism researchers. It provides a comprehensive review of current research literature, including bibliography analysis and systematic content analysis, highlights key themes, identifies new trends, and examines the development of AR technologies in tourism between 2002 and 2022. In other words, scholars can use this dissertation to point out where, when, and how AR is used to support tourism. This information can help researchers to identify gaps in knowledge, and future research avenues. Additionally, we highlight eight promising directions for the future application of AR in tourism. These areas include the integration of artificial intelligence (AI), big data, and machine learning, which could significantly refine how AR integrates and processes large datasets. There's also potential for more sophisticated user experience (UX) optimization, the rise of virtual tourism in the post-Covid-19 era, and a focus on wearable AR technologies that promise hands-free engagement with attractions.

From a practical standpoint, this thesis serves as a valuable resource for various stakeholders in the tourism industry who are interested in improving the overall tourist experience through the latest Industry 4.0 technologies, particularly AR technology. The thesis identified the most commonly used AR design elements, and discussed their implementation to en-

hance user experience, which can guide tourism product developers to introduce innovative and robust AR-based applications, thereby improving consumer satisfaction, and reducing the technological challenges forced by the industry. Furthermore, this thesis could also be informative to policymakers and tourism authorities regarding the potential benefits of integrating AR into tourism propositions, guiding the formulation of supportive policies and investments in AR technologies, thereby contributing to the growth and sustainability of the tourism sector.

FEZAR's empirical evaluation serves as a model for tourism authorities and application developers looking to integrate AR technology into cultural heritage sites locally. It stands as a testament to the role AR technology can play in enriching cultural heritage experiences, pointing to a future where such technology is standard in tourist navigation.

6.3 Future Work

Since this work stands at the crossroads of several fields of research, as we pointed out in the introduction to this thesis, several research directions are essential to continue improving the tourism experience through the emerging technology of AR. In this section, we will list these future projects, ranging from short-term objectives to long-term goals:

1. **Exploration of web content mining** techniques to dynamically update the information content of points of interest, using data from social networks and tourism platforms to keep descriptions up-to-date and relevant.

2. **Deployment of FEZAR on a wearable AR device** such as smart glasses to enable a hands-free experience. Then, conducting a comparative field study between mobile FEZAR and its wearable equivalent is also planned to evaluate their effectiveness in on-site navigation.

3. **Design and conduct a large-scale empirical study** using theoretical frameworks such as the Unified Theory of Acceptance and Use of Technology (UTAUT) to study user adoption of AR in the context of cultural heritage, which could produce more generalizable findings.

4. **Upgrade UX with AR collaboration and gamification** by integrating collaboration features that encourage group engagement in tourism experiences, while introducing gamification elements to increase fun and interactivity within our FEZAR solution. This dual approach aims to create a complete, advanced user experience that exploits the social dynamics of group exploration and the addictive appeal of engaging games.

5. **The integration of generative AI models** to optimize user interactions by using natural language processing (NLP) techniques and automating AR content generation. This approach transforms visitors from mere consumers of content into active participants, as generative AI enables them to generate virtual content in real-time. On the other hand, a visitor could ask questions about a historic site in their own words and receive personalized information generated on the spot by the AI bot.

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Appendix A

Expert Evaluation Form

Personal information

Full name :

Age:

Function:

Affiliation:

Email :

Tel number (optional) : __/___/___/___/___/___/___/___/

Gender: ○ Homme ○ Femme

Your skills in :

	Novice	Beginner	Intermediate	Advanced	Professional
Android	☐	☐	☐	☐	☐
Imaging	☐	☐	☐	☐	☐
Augmented reality	☐	☐	☐	☐	☐
Mobile interface	☐	☐	☐	☐	☐

Liability waiver

I authorize the University of Sidi Mohammed Ben Abdellah in Fez to take note of my comments during the heuristic evaluation for usability or user experience testing of the Android augmented reality prototype, with my full attention and personal awareness of my physical condition and health.

I understand that my personal information will not be shared with third parties.

Having such knowledge, I hereby acknowledge that I understand that other students, teachers or stakeholders involved in the User Augmented Reality Application for Tourism project may have access to my evaluation notes, and that I may be quoted with or without reference to my name in internal presentations and documents.

◉ J'ai lu ce qui précède et j'en comprends parfaitement le contenu :

Signature: _____ Date : ____/_____/____

Test sequence

Please examine the interface independently to familiarize yourself with the application, then perform the following representative tasks:

1. Load and view the monuments around you on your application screen.
2. If you're near a historic monument, explore its information (image, description, distance, etc.) using the prototype.
3. If you get lost in the Medina, can you find your position (coordinates) and destination using the prototype?
4. Select a category of monuments to view, mark the number of visible locations, explore all the monuments included and search for any missing ones.
5. You want to visit "Bou Inania" and you only know it's a MEDERSA, go there with the prototype.
6. Get an update on how far you are from Medersa 'Bou Inania' when you're out and about (Move a few meters)
7. Explore the historic "mosques" that surround you, within a 7 km radius.
8. View all 3D markers, then view only "Fondouk" markers, then view markers from various locations (others).
9. Disable GPS and network data or Wifi network, then restart the prototype. Is the application useful for correcting errors?

Performing these tasks would allow evaluators to identify the set of usability issues in our prototype's augmented reality interface.

Usability evaluation form

(1) = Not a usability problem at all	**(2) = Not important: set later**	***(3)* = Minor problem: low priority**	***(4)* = major problem: high priority**
(5) = Usability disaster: immediate remedial action is imperative.			

Task *N°* :	Problem encountered (issues)	Severity (1 à 5)	Comments / suggestions
1)			
2)			
3)			
4)			
5)			
6)			
7)			
8)			
9)			

P.S: Please reply in English, Thank you. 😊

Appendix B

User Evaluation Questionnaires

B.1 Experimental Group : FEZAR

FEZAR Questionnaire

To thank you for your time and effort, you will receive the premium retail version of the app for free once it goes live.
Please rate the following features based on your experience:

* Indique une question obligatoire

1. Adresse e-mail *

2. Full name : *

3. Gender: *

Une seule réponse possible.

- ◯ Man
- ◯ Women

4. Age : *

5. Phone : *

6. Occupation

7. The language used on your Android mobile? *

Une seule réponse possible.

- ◯ Français
- ◯ English
- ◯ العربية
- ◯ ⵜⴰⵎⴰⵣⵉⵖⵜ
- ◯ Autre : _____

8. Have you ever used an augmented reality app? *

Une seule réponse possible.

- ◯ Yes
- ◯ Nope
- ◯ What is augmented reality?

9. Before this experience, have you ever visited the monument of "BAB SEMMARINE"? *

Une seule réponse possible.

- ◯ Yes
- ◯ Nope

10. if so, could you easily visit it on your own, without the need for a navigation app?

Une seule réponse possible.

- ◯ Yes
- ◯ Nope

11. I authorize the University of Sidi Mohammed Ben Abdellah in Fez to take note of my comments during the heuristic evaluation for the usability or user experience tests of the Android prototype in augmented reality, with all my attention and conscience personal about my physical condition and my health. I understand that my personal information will not be shared with third parties. Having such knowledge, I hereby acknowledge that I understand that other students, teachers or stakeholders involved in the Tourism User Augmented Reality Application project may have access to my evaluation scores, and that I may be quoted with or without reference to my name in internal presentations and documents. *

Une seule réponse possible.

- ◯ I have read the above and fully understand its content:

Passer à la question 12

System usability

12. Rate your overall impression of the usefulness of the system: *

Une seule réponse possible.

- ◯ very useless
- ◯ rather useless
- ◯ Rather useful
- ◯ Very useful

13. Rate the usefulness of each of the following features: *

Une seule réponse possible par ligne.

	very useless	rather useless	Rather useful	Very useful
Markers representing monuments	◯	◯	◯	◯
distance adjuster	◯	◯	◯	◯
Monument menu	◯	◯	◯	◯
Radar	◯	◯	◯	◯
Navigation indicator	◯	◯	◯	◯
Description of monuments (information)	◯	◯	◯	◯
Documentation	◯	◯	◯	◯

14. Was it easy to understand how to use the app? *

Une seule réponse possible.

- ◯ Very difficult
- ◯ Rather difficult
- ◯ Fairly easy
- ◯ Very easy

15. I quickly understood each function of the following elements: *

Une seule réponse possible par ligne.

	Disagree	Rather disagree	Somewhat agree	Totally agree
Monument markers	◯	◯	◯	◯
distance adjuster	◯	◯	◯	◯
Monument menu	◯	◯	◯	◯
Radar	◯	◯	◯	◯
Navigation indicator	◯	◯	◯	◯
Description of monuments (information)	◯	◯	◯	◯
Documentation	◯	◯	◯	◯

16. Was the application easy to use and handle? *

Une seule réponse possible.

- ◯ Very difficult
- ◯ Rather difficult
- ◯ Fairly easy
- ◯ Very easy

17. How did you find the responsiveness of the system? *

Une seule réponse possible.

- ◯ Very slow
- ◯ rather slow
- ◯ Rather fast
- ◯ Very fast

18. Did you make any handling errors when using the system during the visit? *

Une seule réponse possible.

- ◯ 0
- ◯ 1-3
- ◯ More than 3

19. If so, could you correct these manipulation errors?

Une seule réponse possible.

- ◯ Yes of course.
- ◯ No Unfortunately.

20. How satisfied were you with the app's performance on the road? * (performance satisfaction)

Une seule réponse possible.

- ◯ Very unsatisfied
- ◯ Rather dissatisfied
- ◯ Rather satisfied
- ◯ Very satisfied

21. Was the visit interesting? (General satisfaction) *

Une seule réponse possible.

- Not at all interesting
- Not interesting
- Rather interesting
- Very interesting

22. During the visit, did you feel mentally tired? *

Une seule réponse possible.

- Yes
- Nope

23. During the visit, did you feel physically tired? *

Une seule réponse possible.

- Yes
- Nope

The informative aspect

24. There are enough graphic markers to represent places of interest on the screen: *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

25. There is sufficient historical content on the monuments (tourist information): *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

26. Access to information about the monument was provided directly *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

The Navigation/Orientation aspect

27. How many minutes did the visit last? *

28. Did you manage to reach the destinations easily? *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

29. I found the navigation around the monuments: *

Une seule réponse possible.

- Very difficult
- Rather difficult
- Fairly easy
- Very easy

30. Is the design of the system sufficient to guide you through the visit? *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

The fun aspect

31. You find the visit *

Une seule réponse possible.

- Boring
- Rather boring
- Rather fun
- fun

Before finishing

32. Would you be interested in downloading the current version of the prototype and using it as a digital tourist guide? *

Une seule réponse possible.

- Absolutely
- Yes
- Nope
- Definitely No

33. Would you be interested in downloading an improved version of the prototype and using it as a digital tourist guide if it were made available to you? *

Une seule réponse possible.

- Absolutely
- Yes
- Nope
- Definitely No

34. Were there any things that bothered you? *

Une seule réponse possible.

- Yes
- Nope

35. If yes, what are they?

36. Suggest a feature that you think would improve the visual augmented reality prototype:

37. If the augmented reality application were purchasable, how much would you pay for it (in dirhams)?

Ce contenu n'est ni rédigé, ni cautionné par Google.

Google Forms

B.2 Control Goup : GMAP

GMAP Questionnaire

To thank you for your time and effort, you will receive the premium retail version of the app for free once it goes live.
Please rate the following features based on your experience:

* Indique une question obligatoire

1. Adresse e-mail *

2. Full name : *

3. Sex: *

Une seule réponse possible.

- ◯ Male
- ◯ Women

4. Age : *

5. Telephone : *

6. Occupation

7. The language used on your Android mobile? *

Une seule réponse possible.

- ◯ Français
- ◯ French
- ◯ العربية
- ◯ ⵜⴰⵎⴰⵣⵉⵖⵜ
- ◯ Autre : _____

8. Have you ever used an augmented reality app? *

Une seule réponse possible.

- ◯ Yes
- ◯ Nope
- ◯ What is augmented reality?

9. Before this experience, have you ever visited the monument of "BAB SEMMARINE"? *

Une seule réponse possible.

- ◯ Yes
- ◯ Nope

10. if so, could you easily visit it on your own, without the need for a navigation app?

Une seule réponse possible.

- ◯ Yes
- ◯ Nope

11. I authorize the University of Sidi Mohammed Ben Abdellah in Fez to take note of my comments during the heuristic evaluation for the usability or user experience tests of the Android prototype in augmented reality, with all my attention and conscience personal about my physical condition and my health. I understand that my personal information will not be shared with third parties. Having such knowledge, I hereby acknowledge that I understand that other students, teachers or stakeholders involved in the Tourism User Augmented Reality Application project may have access to my evaluation scores, and that I may be quoted with or without reference to my name in internal presentations and documents. *

Une seule réponse possible.

- ( ) I have read the above and fully understand its content:

Passer à la question 12

System usability

12. Rate your overall impression of the usefulness of the system: *

Une seule réponse possible.

- ( ) very useless
- ( ) rather useless
- ( ) Rather useful
- ( ) Very useful

13. Was it easy to understand how to use the app? *

Une seule réponse possible.

- ( ) Very difficult
- ( ) Rather difficult
- ( ) Fairly easy
- ( ) Very easy

14. Was the system easy to use and handle? *

Une seule réponse possible.

- ( ) Very difficult
- ( ) Rather difficult
- ( ) Fairly easy
- ( ) Very easy

15. How did you find the responsiveness of the system? *

Une seule réponse possible.

- ( ) Very slow
- ( ) rather slow
- ( ) Rather fast
- ( ) Very fast

16. Did you make any handling errors when using the system during the visit? *

Une seule réponse possible.

- ( ) 0
- ( ) 1-3
- ( ) More than 3

17. If so, could you correct these manipulation errors?

Une seule réponse possible.

- ( ) Yes of course.
- ( ) No Unfortunately.

18. How satisfied were you with the system's performance on the road? (performance satisfaction) *

Une seule réponse possible.

- Very unsatisfied
- Rather dissatisfied
- Rather satisfied
- Very satisfied

19. Was the visit interesting? (General satisfaction) *

Une seule réponse possible.

- Not at all interesting
- Not interesting
- Rather interesting
- Very interesting

20. During the visit, did you feel mentally tired? *

Une seule réponse possible.

- Yes
- Nope

21. During the visit, did you feel physically tired? *

Une seule réponse possible.

- Yes
- Nope

The informative aspect

22. There are enough graphic markers to represent places of interest on the screen: *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

23. There is sufficient historical content on the monuments (tourist information): *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

24. Access to information about the monument was provided directly *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

The Navigation/Orientation aspect

25. How many minutes did the visit last? *

26. Did you manage to reach the destinations easily? *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

27. I found the navigation around the monuments: *

Une seule réponse possible.

- Very difficult
- Rather difficult
- Fairly easy
- Very easy

28. Is the design of the system sufficient to guide you through the visit? *

Une seule réponse possible.

- not agree at all
- Rather disagree
- Somewhat agree
- Totally agree

The fun aspect

29. You find the visit *

Une seule réponse possible.

- Boring
- Rather boring
- Rather fun
- fun

Before finishing

30. Were there any things that bothered you? *

Une seule réponse possible.

- Yes
- Nope

31. If yes, what are they?

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