University of Zagreb

Faculty of Geodesy

Iva Cibilić

DEVELOPMENT OF USER-ORIENTED METHODOLOGY OF USABILITY OF AUGMENTED MAPS BASED ON CARTOGRAPHIC COMMUNICATION OF TOURIST MAPS

DOCTORAL THESIS

Zagreb, 2026

University of Zagreb

Faculty of Geodesy

Iva Cibilić

DEVELOPMENT OF USER-ORIENTED METHODOLOGY OF USABILITY OF AUGMENTED MAPS BASED ON CARTOGRAPHIC COMMUNICATION OF TOURIST MAPS

DOCTORAL THESIS

Mentor:

Assoc. Prof. Vesna Poslončec-Petrić, PhD

Zagreb, 2026

Sveučilište u Zagrebu

Geodetski fakultet

Iva Cibilić

RAZVOJ KORISNIČKI USMJERENE METODOLOGIJE UPOTREBLJIVOSTI PROŠIRENIH KARATA ZASNOVANE NA KARTOGRAFSKOJ KOMUNIKACIJI TURISTIČKIH KARATA

DOKTORSKI RAD

Mentorica:

izv. prof. dr. sc. Vesna Poslončec-Petrić

Zagreb, 2026

STATEMENT OF ORIGINALITY

I declare that this doctoral thesis *Development of User-Oriented Methodology of Usability of Augmented Maps Based on Cartographic Communication of Tourist Maps* represents my original work and that I have used no other sources beside those that are referenced within it.

Zagreb, xx.xx.2026

Iva Cibilić

GENERAL INFORMATION ABOUT THE DOCTORAL DISSERTATION

I. AUTHOR

Full name:	Iva Cibilić
Date and place of birth:	10 November 1995, Dubrovnik
Current employment:	Research and Teaching Assistant at Faculty of Geodesy, University of Zagreb, Zagreb, Croatia

II. DOCTORAL THESIS

Title:	Development of User-Oriented Methodology of Usability of Augmented Maps Based on Cartographic Communication of Tourist Maps
Institution and place where the thesis have been made:	University of Zagreb – Faculty of Geodesy, Zagreb, Croatia
Mentor:	Assoc. Prof. Vesna Poslončec-Petrić, PhD
Thesis serial number:	
Scientific area:	Technical Sciences
Scientific field:	Geodesy
Scientific branch:	Cartography
Number of pages:	129
Number of appendices:	5
Number of figures:	24
Number of tables:	16
Number of references:	254

III. EVALUATION AND DEFENCE

Date of the public defence of the doctoral thesis proposal: 3 October 2024
Date of doctoral thesis proposal acceptance by the Faculty Council: 31 October 2024
Date of doctoral thesis proposal acceptance by the University Senate: 16 December 2024
Committee for doctoral thesis evaluation: Assoc. Prof. Ivka Kljajić, PhD
Prof. Željko Bačić, PhD
Asst. Prof. Dušan Petrovič, PhD*
Date of Thesis acceptance by the Faculty Council Decision:
Committee for doctoral thesis defence:

Date of the public defence of the doctoral thesis:

* University of Ljubljana, Faculty of Civil Engineering and Geodesy, Slovenia

INORMATION ABOUT THE MENTOR

Assoc. Prof. Vesna Poslončec-Petrić, PhD

University of Zagreb

Faculty of Geodesy

Institute of Cartography and Photogrammetry

Chair of Cartography

Kačićeva 26, 10000 Zagreb

vesna.posloncec-petric@geof.unizg.hr

Zahvala

ABSTRACT

This doctoral thesis examines augmented tourist maps as a cartographic design approach for national park tourism. It addresses a core cartographic challenge: how to provide rich thematic information without overcrowding the printed map or compromising readability. This thesis argues that a deliberate distribution of information between a printed base map and a virtual overlay can reduce map clutter on paper while maintaining effective map use, and evaluates this proposition through a user-oriented methodology aligned with ISO principles.

The research is set in the context of Croatian national park tourist maps. It begins with an analysis of existing analogue map products to identify recurring communication weaknesses, with particular attention to symbol use and thematic density. User priorities and perceptions of map content are then collected to inform design requirements. On this basis, a cartographically grounded augmented map concept is developed, using a deliberate printed–virtual layer split to control symbol density and clarify thematic emphasis. The concept is refined through expert review and subsequently assessed through comparative user-based usability testing of the analogue and augmented map conditions.

The findings indicate that the proposed augmented map concept can support map use without undermining overall usability. Performance was broadly comparable between conditions, while the augmented stimuli offered efficiency advantages and facilitated access to selected information without increasing perceived complexity. At the same time, the benefits of the virtual layer were not uniform, highlighting the importance of careful layer allocation, consistent visual hierarchy, and managing attention shifts between paper and screen.

This thesis contributes a repeatable, cartographically grounded and user-oriented methodology for designing and evaluating augmented tourist maps, and provides practical guidance on when and how printed–virtual layer splitting can add value in national park mapping contexts.

Keywords: augmented maps; augmented reality; tourist maps; cartographic communication; usability; user-centred design; pictograms; Croatian national parks.

SAŽETAK

Ovaj doktorski rad istražuje proširene karte kroz kartografski pristup izrade turističkih karata nacionalnih parkova. Istraživanje je usmjereno na pitanje kako pružiti bogat tematski sadržaj bez opterećivanja tiskane karte i narušavanja čitljivosti. Polazi se od teze da promišljena raspodjela informacija između tiskane karte i virtualnog sloja može smanjiti opterećenost karte na papiru uz zadržavanje učinkovite upotrebe karte, a ta se pretpostavka ispituje kroz korisnički usmjerenu metodologiju usklađenom s ISO načelima.

Istraživanje je započelo analizom postojećih analognih karata hrvatskih nacionalnih parkova radi utvrđivanja njihovih nedostataka, uz poseban naglasak na upotrebi kartografskih znakova i njihovu distribuciju. Zatim su prikupljeni uvidi u korisničko razumijevanje kartografskog sadržaja te njihove prioritete u pogledu sadržaja karte kako bi se oblikovali zahtjevi za njihovo poboljšanje. Na toj je osnovi razvijen kartografski utemeljen koncept proširene karte, pri čemu se namjerno primijenila podjela sadržaja između tiskane karte i virtualnog sloja kako bi se bolje kontrolirao raspored kartografskih znakova i ustanovila hijerarhija među njima. Koncept proširene karte dodatno je unaprijeđen kroz stručnu evaluaciju te je provedeno korisničko ispitivanje upotrebljivosti takve proširene karte kroz usporedbu s analognom kartom.

Rezultati upućuju da predloženi koncept proširene karte podržava upotrebu karte bez narušavanja ukupne upotrebljivosti. Učinak je bio podjednak između dva uvjeta, dok je proširena karta pokazala prednost u učinkovitosti te olakšanom pristupu informacijama bez povećanja složenosti. Istodobno, korisnost virtualnog sloja nije bila ujednačena, što naglašava važnost pažljive raspodjele sadržaja po slojevima, dosljedne vizualne hijerarhije i olakšanim prebacivanjem pažnje između papira i ekrana.

Ovaj rad doprinosi kartografski utemeljenom i korisnički usmjerenom metodologijom za izradu i ispitivanje proširenih turističkih karata te pruža praktične smjernice o tome kada i kako podjela sadržaja između tiskane i virtualne razine može donijeti dodatnu vrijednost u kontekstu karata nacionalnih parkova.

Ključne riječi: proširene karte; proširena stvarnost; turističke karte; kartografska komunikacija; upotrebljivost; korisnički usmjeren dizajn; piktogrami; hrvatski nacionalni parkovi.

CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AGR	Augmented Geographic Reality
AM	Augmented Map
AR	Augmented Reality
ARE	Augmented Reality Environment
AT	Augmented Territory
AV	Augmented Virtuality
AVE	Augmented Virtual Environment
GIS	Geographic Information System
GPS	Global Positioning System
HCI	Human–Computer Interaction
ISO	International Organization for Standardization
MR	Mixed Reality
POI	Point(s) of Interest
QR-code	Quick Response (code)
RFID	Radio-Frequency Identification
SBSOD	Santa Barbara Sense of Direction (Questionnaire/Scale)
SUS	System Usability Scale
UCD	User-Centred Design
VR	Virtual Reality
XR	Extended Reality

1 INTRODUCTION

Maps are a form of communication, a means of comprehending, articulating, and constructing the human world (Harley, 2009). Cartographic visualisations are typically provided as printed or digital maps, viewed on screens or paper. Map users can interact intuitively and directly with a paper map in a natural and familiar way (Carrera et al., 2017). However, printed maps are static and offer limited interactivity (Asai et al., 2008). This creates a design tension: maps benefit from the clarity and overview of print, but users increasingly expect additional, responsive information.

Augmented Reality (AR) offers a way to extend maps beyond the limitations of paper by using computer vision and interactive display technologies. AR enhances perception of the real environment by adding virtual information (Azuma, 1997), supplementing the real world with virtual objects that appear to coexist in the same physical space. In doing so, it enhances users' interaction and experience in both real and virtual environments (Bobrich and Otto, 2002).

From a navigational perspective, AR systems have often been emphasised as systems for wayfinding and guidance, yet research suggests that "turn-by-turn" aids can reduce deeper spatial learning when users follow instructions without actively processing routes (Ruginski et al., 2019). This challenge is heightened by the fact that AR views differ substantially from traditional graphical user interfaces and bring practical constraints (e.g. screen size, patchy connectivity, short battery life) and contextual challenges (e.g. changes in weather and lighting conditions) that affect attention and interpretation (Çöltekin et al., 2020).

This thesis focuses on augmented maps (AMs): maps on which multiple types of geographic information are superimposed to enhance cartographic information transfer and map reading (Cheng et al., 2022). Research on AMs has progressed from early collaborative and mobile prototypes to approaches that integrate paper maps with digital overlays and updating functions (Bobrich and Otto, 2002; Morrison et al., 2009; Paelke and Sester, 2009; Reilly et al., 2006). More recent work has examined the contribution of AR systems to map reading and improving users' understanding of spatial data (de Almeida Pereira et al., 2017). However, this highlights a cartographic gap: the virtual overlay has not been explicitly framed as a cartographic design strategy, leaving limited evidence on how distributing information between printed and virtual layers influences AM use.

From a cartographic perspective, AMs are promising because they can extend static representations beyond the printed surface. A paper map provides a large, stable display, while AR can serve as a see-through lens that adds information without confining the user to a small mobile screen (Morrison et al., 2009). However, designing semi-virtual cartographic environments requires particularly deliberate choices and the integration of cartographic rules and knowledge (Amorim and Schmidt, 2021; Bednarczyk, 2017). At the same time, there is still limited evidence on how layer allocation and graphic design choices (such as symbol hierarchy and attention switching between paper and screen) affect AM usability outcomes, particularly effectiveness and efficiency. There is also limited understanding of the user requirements that must be met to ensure efficient work with AR in general, and AMs in particular (Cheng et al., 2022). This highlights the need for user-oriented evaluation of AMs that links specific cartographic design decisions to measurable usability outcomes. This aligns with a broader trend in contemporary cartography and geovisualisation: map design is increasingly user-oriented, treating the user as central to how the cartographic message is formed and evaluated (Roth, 2019; Slocum et al., 2001). Effective spatial communication depends on how relevant information is shaped and cognitively processed (MacEachren, 1995), and the discipline's core focus remains improving the effectiveness of spatial information communication (Robinson et al., 2023).

These issues are especially salient in tourism contexts, where maps support tourism activities by helping visitors organise plans and access information in unfamiliar places (Airikka and Masoodian, 2019; Jancewicz and Borowicz, 2017; Özogul and Baran, 2016). This also applies to nature-based destinations such as national parks (Taczanowska et al., 2019; Yan and Lee, 2015). As tourists increasingly rely on mobile devices for planning and in-situ decision-making, destinations are encouraged to adopt technologies that enhance experiences and competitiveness (Ghaderi et al., 2019; Han et al., 2013; Law et al., 2018). The potential to enrich map use through AR technology is growing, but it also introduces new interaction demands and can alter how users perceive map content. As pictograms are common information carriers in tourist maps, their placement, selection, and generalisation become critical design issues in Ams - particularly when the goal is to distribute content between layers without increasing confusion or attention costs. The need for further research on user experience in tourism mapping remains clear, especially as AR products become more common in this domain (Han et al., 2018; Medynska-Gulij, 2003).

For these reasons, this thesis adopts a user-oriented approach grounded in usability engineering and user-centred design (UCD). UCD involves users in the development stages to enhance the usability of the final product. By involving users in the production process, the effectiveness of the product - its quality for the user - can improve significantly. Consistent with calls for formal and repeatable user-oriented processes in cartography (Roth, 2019), the thesis prioritises formative evaluation and combines expert-based, theory-based, and user-based evaluation methods, creating a multi-phase methodology that links evidence about communication and user priorities to design decisions and controlled usability evaluation (Van Elzakker, 2004).

The purpose of this thesis is to develop and evaluate a cartographically grounded augmented tourist map concept using a user-oriented, ISO-aligned methodology, and to test whether distributing thematic information between a printed base map and a virtual overlay can improve map use without compromising overall usability.

To address this purpose, this thesis pursues two objectives:

O1. To study and analyse the existing symbols used on Croatian national park analogue tourist maps and assess their efficacy in transmitting cartographic messages.

O2. To design and evaluate a cartographically grounded augmented tourist map concept for Croatian national park maps based on a printed-virtual layer split, applying cartography-based design principles and assessing cartographic communication and usability using user-oriented outcomes.

Based on these objectives, two hypotheses have been formulated:

H1. Augmented tourist maps improve the exact position of objects shown on the map using pictograms without disturbing the cartographic balance.

H2. Virtual content on augmented maps improves the user's perception of the map content.

Here, perception is operationalised through standard usability outcomes: effectiveness, efficiency, and satisfaction (perceived usability), captured through task performance measures and post-use usability ratings.

To address the research objectives in a way that is both cartographically grounded and empirically testable, the thesis applies a five-phase user-oriented methodology aligned with ISO UCD logic (competitive analysis → user needs assessment → conceptual design and prototyping → expert review → user-based usability evaluation), with formative feedback loops before the final benchmark comparison. A key feature of this approach is a matched-stimuli design: the analogue and augmented map versions share the same overall content and symbol logic, while differing primarily in the distribution of selected POI (point of interest) pictograms between the printed layer and the virtual overlay, enabling a fair comparison of the augmentation concept.

To maintain interpretability in the evaluation, this thesis focuses on a specific cartographically grounded augmented map concept based on a printed–virtual layer split, implemented as a marker-based, static 2D overlay coordinated with a printed base map. The findings therefore pertain to this layered design approach rather than to AR systems in general or to more complex implementations such as location-based or 3D augmentation.

This thesis makes two main contributions. First, it develops and demonstrates a repeatable, ISO-aligned user-oriented methodology for augmented tourist maps, showing how evidence about cartographic communication weaknesses and user priorities can be translated into explicit design requirements, refined through an expert checkpoint, and then evaluated through a fair, benchmarked usability comparison. Second, it provides practical insight into augmented maps: distributing thematic content between a printed base and a virtual overlay can preserve overall usability while improving efficiency, but the concept adds value only when the two layers function as a coherent visual system.

This thesis is organised as follows. Chapter 2 reviews the theoretical and methodological foundations that frame the study, including cartographic communication, relevant work on augmented reality and augmented maps, and usability concepts. Chapter 3 presents the research design and the ISO-aligned, five-phase, user-oriented methodology, describing the study materials, participants, instruments, procedures, and analysis approach. Chapter 4 reports the results for each phase, showing how early evidence informed the map concept and culminating in the benchmark comparison between the analogue and augmented map conditions. Chapter 5 discusses the findings in relation to cartographic communication and usability outcomes, clarifies when the printed - virtual layer split adds value, and outlines design implications and study limitations. Chapter 6 concludes the thesis by synthesising the main contributions, evaluating the hypotheses, and identifying directions for future research and development of cartographically grounded augmented tourist maps.

2 BACKGROUND

2.1 Cartographic communication

"Cartography is the science, technology, and art of cartographic mapping and using maps" (Lapaine et al., 2021). This definition demonstrates that research in cartography is an interdisciplinary field, although this perspective has not always been recognised. Since the mid-20th century, cartographers have been trying to distinguish cartography from geography and artistic visualisations. They advocated for cartography as a professional, standardised formal practice rather than an art, and the focus of the field shifted from production efficiency and graphic design towards map functionality (MacEachren, 1995), which has largely persisted to the present.

Robinson (1952) was among the first to explore the concept of cartography as a science of communication. He stated that communication is the primary function of the map and depends on its visual appearance, which relates to the cartographer's specific design decisions. Robinson emphasised that, to improve the map's function (i.e., its communication), cartographers must understand how their choices affect the map user, and the best way to achieve this is through "careful and systematic study". This work is considered foundational to cartographic communication and provides a theoretical framework for cartography as a communication science.

2.1.1 Communication models

The most influential description of a cartographic communication model was provided by Koláčný (1969). He argued that map production and map use should be understood as two parts of a single process through which cartographic information is created, transmitted, and interpreted (Montello, 2002). Cartographic information refers to the meaning of the cartographer's representation of the real world, that is, the message encoded in the map. It is distinct from map content, which is the set of graphic elements perceived by the user. The model treats production and map use as one process in which cartographic information is created, communicated, and has an effect. This process, shown in Figure 2.1, is called the communication of cartographic information.

Koláčný's model of cartography as a communication system reflects the thinking of cartographers in the late 1960s and 1970s, who focused on understanding procedures and methods to enhance map effectiveness through good design. Communication became the primary function of cartography, and the map was considered the medium of that communication.

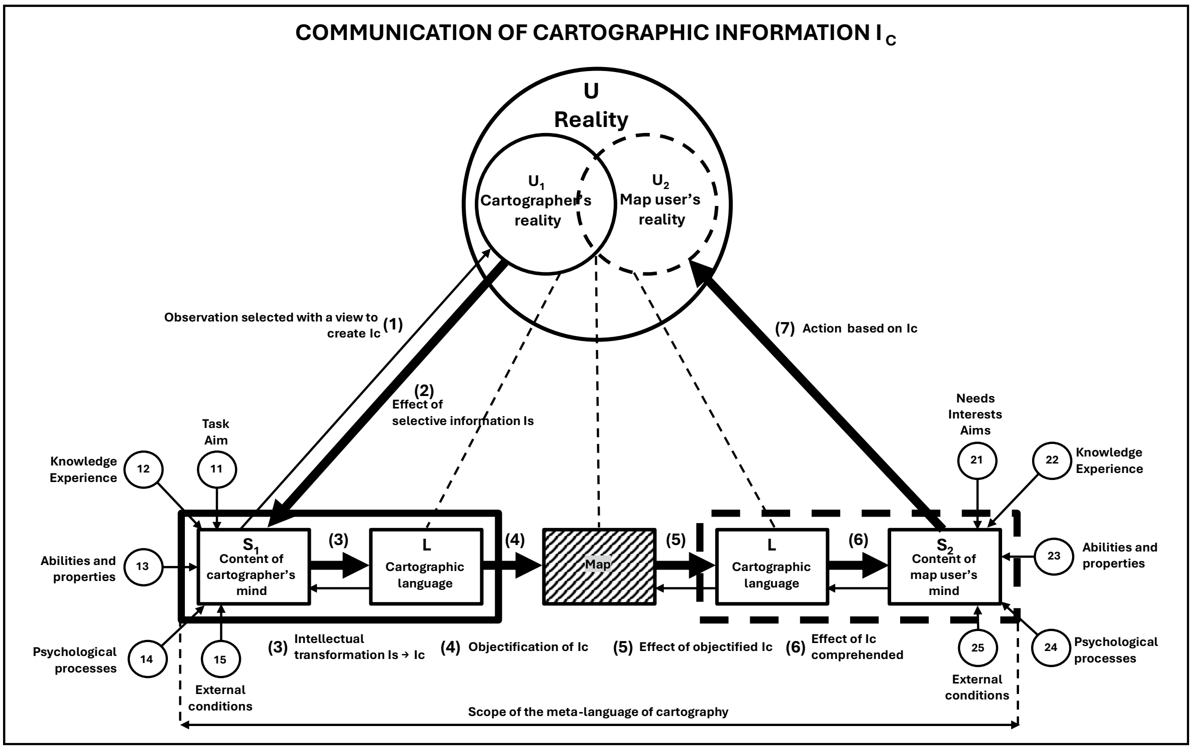


Figure 2.1 Koláčný's communication of cartographic information model (adapted from Koláčný, 1969)

However, not everyone agreed with this approach. Salichtchev (1970) considered the communication science approach too technical and inseparable from the mathematical theory of information. He also viewed cartography as a much broader field: "a subject of spatial distribution, combinations, and interdependence of nature and society (and their changes over time) by means of representation through a special symbolic system – cartographic symbols" (Salichtchev, 1970). Guelke (1976) also criticised the communication paradigm, arguing that cartographers should not, by becoming specialists in graphic communication, neglect the geographical context. This opinion was well received within the community.

Morrison (1976) presented a more positive view of cartography as a science, treating it as the systematic transmission of information via maps. For him, scientific work begins with the cartographer's own conceptualisation of geographic space and its features. The focus is on the communication channel itself and thus excludes the reader's perceptual and cognitive processes, such as map reading, interpretation, and analysis. Neglecting the user's ability to receive the intended message is seen as the main limitation of this model, which will be addressed later.

The view of cartography as a communication process has been elaborated by many other authors (Board, 1972; Crampton, 2001; MacEachren, 1995; Montello, 2002; Ostrowski, 2008; Ratajski, 1971). While the details of these depictions vary, all models share a basic structure (Figure 2.2).

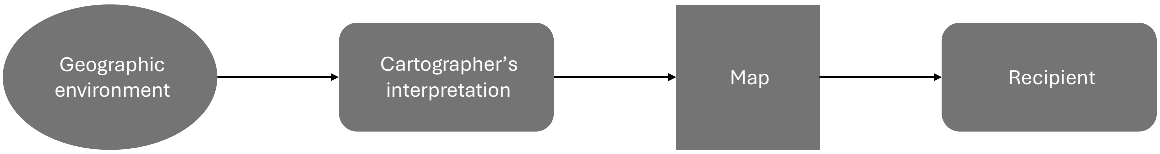


Figure 2.2 General overview of cartography as a process of information communication (adapted from MacEachren, 1995)

The cartographic process begins with the cartographer's understanding of the world and a phenomenon within it. This conception is then encoded in the map, which serves as the medium for a message. Although the map is designed with a preferred interpretation in mind, both the cartographer's intention and the user's interpretation are influenced by cultural, technical, educational, professional, personal, and national backgrounds (Board, 1972). As a result, users may derive meanings the cartographer did not intend, and preferred content may go unnoticed. Maps therefore operate not only through meanings created by cartographers but also through the prior knowledge users bring to interpretation (Guelke, 1976; Petchenik, 1975). Rather than treating the cartographer and the map as neutral transmitters of information, it is more effective to study the perceptual and cognitive processes that contribute to the creation and interpretation of maps (Morrison, 1976; Robinson and Petchenik, 1976).

2.1.2 Cognition and map reading

Cognitive principles are important to cartographers because they help explain why certain map elements work, that is, communicate information effectively (Slocum et al., 2023). Historically, cartographers focused on testing which symbols performed best rather than explaining why they worked. This approach, known as the behaviourist view, treated the human mind as a black box (MacEachren, 1995). Today, a cognitive perspective is more common, aiming to uncover the mechanisms behind effective symbol use.

According to Montello (2002), cognitive cartography involves using both cognitive theories and methods to study maps, and using maps to study human cognition. For him, cognition includes perception, learning, memory, thinking, reasoning, problem-solving, and communication. As Slocum et al. (2023) emphasise, cognition and perception are not the same:

perception involves the initial sensory detection of symbols (such as presence, symbol size, or colour), while cognition builds on perception and involves interpretation, prior learning, and experience.

Żyszkowska (2015) cites Eckert (1925) as one of the first to recognise the importance of psychological factors in cartography. Eckert argued that effective maps are designed with psychological processes in mind and that readers comprehend them by integrating separate elements into a single, coherent mental image (Eckert, 1925). At that time, map perception was viewed as a stimulus – response process: symbols served as stimuli that elicited visual sensations. Designing maps to optimise this process was considered cartography's basic task.

Within cartographic communication, map perception was treated as one stage in the information transfer process: a reading process defined by a stimulus – response relationship. Information obtained during map use was thought to be stored in memory, and the encoding that occurs during map reading was understood to vary quantitatively (Ratajski, 1971).

According to Board (1978) and Ratajski (1971), map reading operates on two levels. The first is perception, involving the visual acquisition, decoding, and verbalisation of symbols. The second is interpretation, in which visualisation, measurement, analysis, and verification yield mental representations of the depicted reality. From a semiological perspective, Bertin (1967) argued that perceiving a map resembles reading a written text, as maps constitute systems of signs or codes. In his work on graphic expression, Bertin (1967) conducted the first systematic, detailed, and extensive analysis of graphic elements and, on that basis, created a graphic language for visual perception. He offered the following definition: "A graphic representation is the transformation of a thought, of information known in any system of signs, into a graphic system of signs." Bertin's semiotics – the theory of signs – showed cartographers how to make design decisions about cartographic symbols based on harmony between the characteristic features of the data and the cartographic signs.

Freitag (1971) and Hake (1973) describe their models of cartographic processes, in which they also highlight the importance of semiotics in cartographic communication to achieve symbol perception through map use.

Hake (1973) model is among the first to detail map-using activities. It places the purpose of map use at the centre, determining whether the user actively searches or simply browses (passive perception). If no further search is pursued at the end of the diagram, users may proceed to non-cartographic activities (e.g., wayfinding).

Robinson and Petchenik (1976) provided the most comprehensive synthesis of communication theory and psychophysical results. In their view, the communication framework undervalued the map user and therefore failed to examine the human cognitive system adequately.

As digital technologies in cartography and geographic information systems advanced, these limitations became apparent. By the mid-1990s, cartographers shifted their research focus from the cartographic communication model to the concept of cartographic visualisation.

2.1.3 From communication to geovisualization

Dibiase (1990) was the first to connect cartographic communication and visualisation through the visualisation framework (Figure 2.3). He described a four-stage research sequence: (1) explore the data to identify key questions, (2) test apparent relationships against a formal hypothesis, (3) synthesise or generalise the results, and (4) communicate the work professionally. The process begins as an individual, private activity. As the audience expands, the researcher gradually shifts from answering research questions to communicating ideas to others. According to the author, visualisation deveops alongside the transition from the private to the public realms. Visual thinking involves generating ideas by creating, inspecting, and interpreting displays of previously unseen patterns, while visual communication effectively distributes those ideas in visual form. The emphasis in this framework is on the role of the map in the research process (MacEachren, 1994), distinguishing between maps that support personal visual thinking during investigation and maps that facilitate the public visual communication of research results. Thus, visualisation should be regarded less as an innovation and more as a research tool mediating between visual communication and visual thinking.

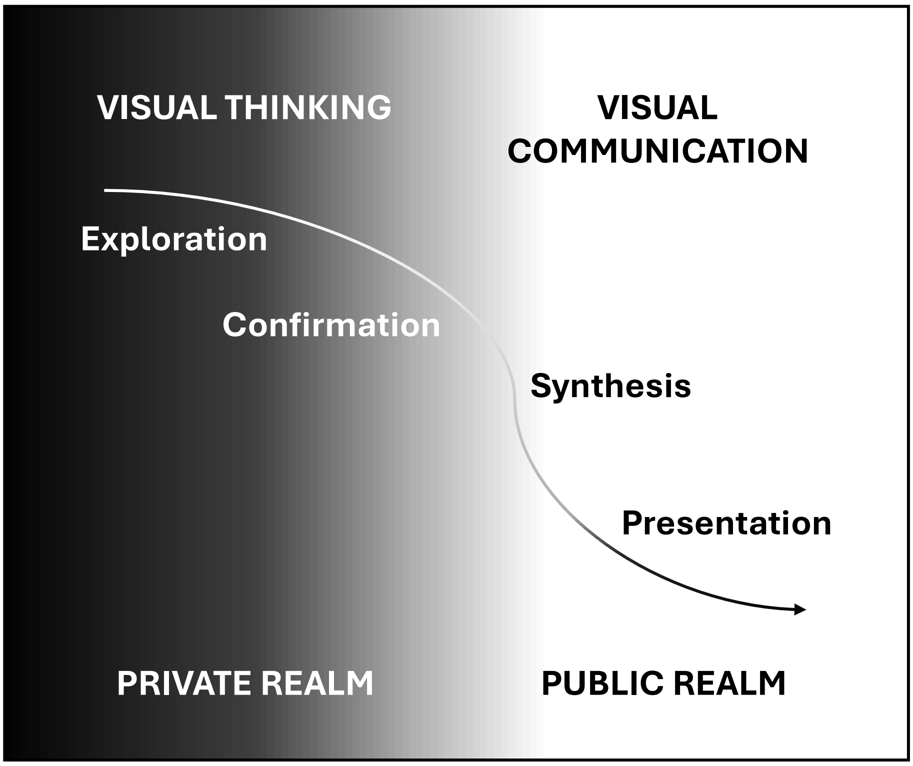


Figure 2.3 DiBiase's depiction of visualization as a tool of scientific research (adapted from Dibiase, 1990)

Taylor (1991) defined visualisation from a technological perspective as a domain of computer graphics aimed at addressing the analytical and communication challenges of visual representation. From a cartographic perspective, the emphasis on new computing technologies has overshadowed cognitive and communication issues. He argues that progress in all three domains – cognition, communication, and new computer technologies – is essential for effective cartographic visualisation.

These frameworks suggest that visualisation encompasses both analysis or visual thinking and communication or presentation, implying that communication is a subcomponent of visualisation. From this viewpoint, one might claim that visualisation is equivalent to cartography, making it appear as though communication has lost its role and visualisation does not introduce anything new (MacEachren, 1994). This perspective risks cartography missing the broader "scientific visualisation" movement. Later, Taylor (1994) explicitly argues against equating visualisation and cartography. He regards visualisation as a distinct development within cartography, and in science more generally, that affects cognition and analysis, communication, and formalism (new computer technologies).

Building on this approach, MacEachren (1994) states that visualisation, like communication, concerns the use of maps, not just their creation. The core idea of MacEachren's visualisation model is that map use can be represented as a three-dimensional space. This space is defined by three continua – wholes that are infinitely divisible (Figure 2.4):

- The first continuum ranges from private map use (where an individual creates a map tailored to personal needs) to public map use (where previously prepared maps are made available to a broad audience).
- The second continuum ranges from map use aimed at discovering the unknown (where a user may begin with a general goal, seeking something "interesting") to map use focused on presenting the known (where a user seeks precisely specified information).
- The third continuum ranges from map use with high human-map interaction (where the user can manipulate the map) to low interaction (where the user has limited ability to change the display).

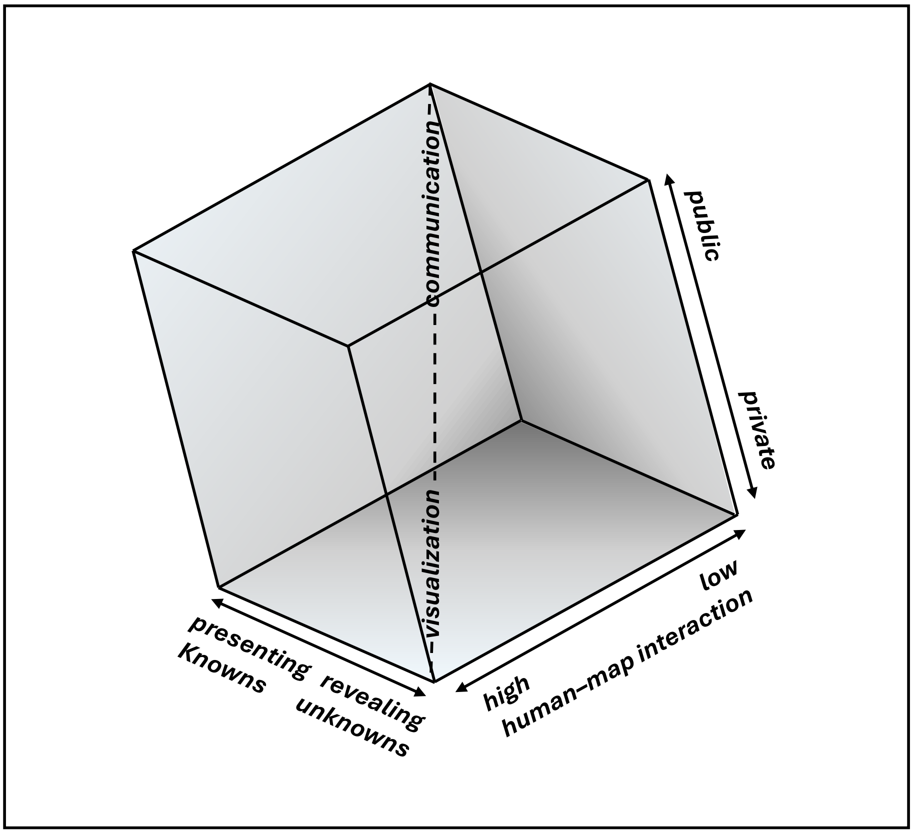


Figure 2.4 MacEachren's representation of three-dimensional map-use cube (adapted from MacEachren, 1994)

In this framework, visualisation complements communication. All map use involves both visualisation (defined as prompting visual thinking and knowledge construction) and communication (defined as the transfer of information), though the balance between them may vary. Communication remains present even when visualisation is the main objective. Similarly, even a strictly communication-oriented map can trigger mental visualisation. This definition clarifies that maps designed to transfer knowledge from a few to many differ in goals and design principles from maps intended to support spatial thinking by individuals or small groups. This approach keeps visualisation conceptually distinct and allows cartography to engage meaningfully with the broader scientific visualisation field.

Research shifting from a communication paradigm to (geo)visualisation development has paralleled psychological advancements. In the early 1990s, work on map perception merged with cognitive psychology and cognitive science. Anchored in an information-processing paradigm, this orientation accepted maps as cognitive artefacts and as objects that can be modelled accordingly. From this standpoint, perception is one component of the broader cognitive system; understanding maps extends beyond simple stimulus – response reactions to higher-level processes such as interpretation, problem solving, and building spatial knowledge.

MacEachren (1995) synthesised experimental and cognitive cartography, linking how maps are "seen" to how they are "understood" within a broader concept of cartographic visualisation. With digital, animated, 3D, and navigational maps proliferating, research has shifted from low-level perceptual issues associated with visual perception to higher-level cognition associated with knowledge creation and spatial decision-making. Today, perception remains central to both communication and visualisation due to the increased popularisation of maps, their greater availability, and the emergence of new forms of maps, renewing interest in how people perceive, interpret, and think with maps.

As cartography entered the digital era, geovisualisation reframed maps from static communication products to interactive, explorative tools (Roth, 2013). This repositioned the map as an instrument for thinking with data, not only for presenting it (MacEachren and Kraak, 2001). With the advent of technology, the main medium for accessing spatial information shifted from desktop to mobile devices, where small screens and constant internet access changed the conditions of map use. The concept of mobile cartography was introduced by Reichenbacher (2001) from a GIS perspective. His conceptual framework emphasises the user, context, and tasks as the main elements responsible for the adaptation of this kind of visualisation. Although technological conditions have changed, the main concept remains the same; today, we understand mobile cartography as "the technology, visualisation, transmission and usage of spatial data fitted for the special circumstances and capabilities of mobile devices as well as a mobile usage environment" (Schulz et al., 2021). Although the idea was proposed decades ago, adaptive map visualisation that uses context data from smartphone sensors is still not fully developed (Reichenbacher and Bartling, 2023). Commonly used mobile apps and services can also lead to problems such as information overload, exclusion, excessive automation, dependency on automated support or reduced user control (Thrash et al., 2019).

2.1.4 Implications for mobile maps

Displaying relevant geographic information on small screens remains challenging. The main issue with mobile maps is complexity, as they must present large amounts of data within limited screen space. To address cluttered and visually complex displays, Swienty et al. (2008) introduced a method that highlights important information to guide users' attention in mobile settings. Their approach filters the map's content to reduce clutter and uses visual cues to emphasise key features, improving usability.

Compared to paper or static online maps, mobile maps offer a basic level of map automation. Maps can now support everyday activities by providing real-time updates and designs that adapt when their use context changes. However, these new use contexts often generate additional cognitive load in noisy and highly dynamic environments (Griffin et al., 2024). This increased cognitive load is also caused by mobile device design constraints, such as small screens (Griffin et al., 2017; Schulz et al., 2021).

A growing cognitive literature warns that automation in mobile navigation can reduce spatial learning. Empirical studies indicate that heavy reliance on digital navigation tools, such as GPS and automated route guidance, is associated with lower attention to the environment, which impedes the development of mental spatial representations and reduces overall spatial abilities (Brügger et al., 2019; Burnett and Lee, 2005; Münzer et al., 2006; Ruginski et al., 2019). Multiple researchers now provide compelling evidence that this dependence on navigation assistance not only disrupts learning but also has measurable impacts on cognitive processes (Cheng et al., 2022; Dong et al., 2022; Ishikawa, 2019; Kapaj et al., 2021; Ruginski et al., 2019). For instance, Ruginski et al. (2019) demonstrated that longer-term GPS use is linked to deficits in spatial transformation skills such as mental rotation and perspective-taking, abilities crucial for learning and navigating unfamiliar environments without technological aid. One likely explanation is that automated positioning reduces the incentive to encode spatial information and discourages active engagement with surroundings (Ruginski et al., 2019).

Similar patterns have emerged in work by Toru Ishikawa (2019), who identified declines in real-world navigation and wayfinding performance in frequent digital map users.

The context in which mobile maps are used also affects human navigation. Use of modern navigation aids divides users' attention between device and environment, increasing cognitive load (Gardony et al., 2015; Schulz et al., 2021). This divided attention is not only harmful to spatial memory formation but is also associated with navigation behaviours marked by lower efficiency and accuracy (Gardony et al., 2015; Toru Ishikawa et al., 2008). Several researchers urge consideration of these technological consequences, suggesting that degradation of spatial navigation may have extensive implications beyond wayfinding, potentially affecting other aspects of daily life (Bellmund et al., 2018). There is thus a growing consensus that the design of navigation systems should seek a careful balance between automation and user engagement, encouraging users to actively process and interact with their environment rather than passively follow instructions (Brügger et al., 2019; Thrash et al., 2019). The challenge moving forward is to develop interfaces that promote sustained spatial knowledge acquisition and environmental awareness, so that navigation aids supplement rather than supplant users' own learning and spatial reasoning abilities.

Based on previous findings, immersive approaches are a reasonable next step. As geospatial representations have shifted towards 3D, real-time, mixed-reality formats (Azuma, 1997; MacEachren and Kraak, 2001), Augmented Reality appears to be a natural next visualisation medium. By placing virtual cues directly in the user's field of view, AR shows potential to extend human perception of the environment (Azuma, 1997; Çöltekin et al., 2020).

2.2 Augmented reality

Augmented Reality (AR) is a technology that enhances perception of the real environment by adding virtual information (Azuma, 1997). It is best described as part of Milgram's reality-virtuality continuum (Figure 2.5), which presents a purely real environment, consisting only of real objects, at one end, and a purely virtual environment, consisting only of virtual objects, at the other (Milgram and Kishino, 1994). Any environment blending real and virtual objects is considered mixed reality (MR). Mixed reality environments in which the real world is augmented with virtual content are called augmented reality (AR), while those in which most content is virtual but there is some awareness or inclusion of real-world objects are called augmented virtuality (AV). Virtual reality (VR) environments are considered completely virtual worlds. Extended Reality (XR) is a term used to encompass all these technologies. The terminology defined here will be used consistently throughout the rest of the thesis.

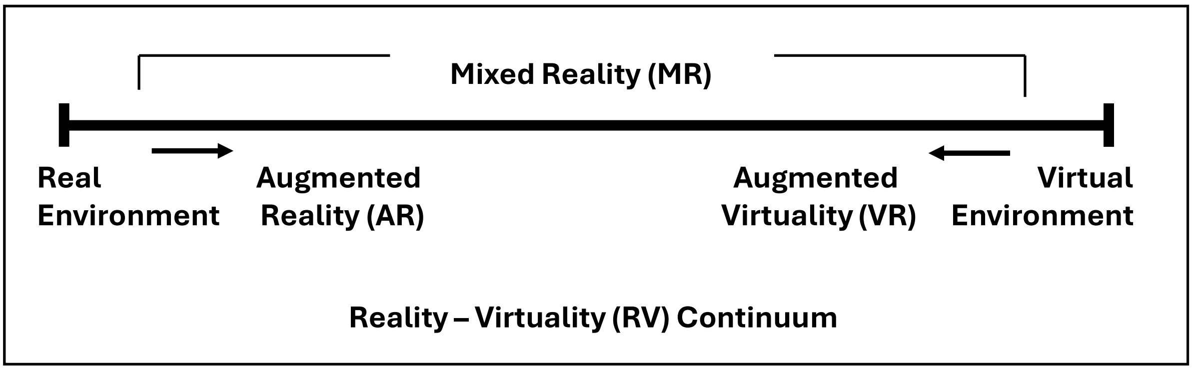


Figure 2.5 Reality-virtuality continuum (adapted from Milgram and Kishino, 1994)

From a geographical perspective, visualisations that use AR can be divided into augmented virtual environments (AVE) and augmented geographic reality (AGR) (Cheng et al., 2022). Cheng et al. further suggest that AGR should be categorised into augmented reality environments (AREs) and augmented maps (AMs), based on the two ways users perceive geographic environments (Figure 2.6).

This distinction aligns with Hugues et al. (2011), who proposed a GIS–AR–specific classification by separating the source of information from its representation. They defined Augmented Maps (AMs) as GIS/map data updates of the display according to user requests, and Augmented Territory (AT) as overlays anchored in the physical environment that support in-situ work by updating geo-located data in time and space. Cheng et al.'s (2022) framework extends this view by emphasising cognitive modes: AREs (conceptually corresponding to AT) augment direct environmental perception, while AMs augment cartographic representations designed for spatial cognition. This thesis adopts Cheng et al.'s categorisation, with the understanding that AMs, the focus of this research, are maps on which multiple types of geographic information (e.g., models and multimedia files) are superimposed to enhance cartographic information transfer and users' spatial cognitive ability. It should also be noted that AR views are highly technology-dependent, usually requiring optical devices for their visualisations. In this thesis, the emphasis is on mobile devices, although this is not always the case.

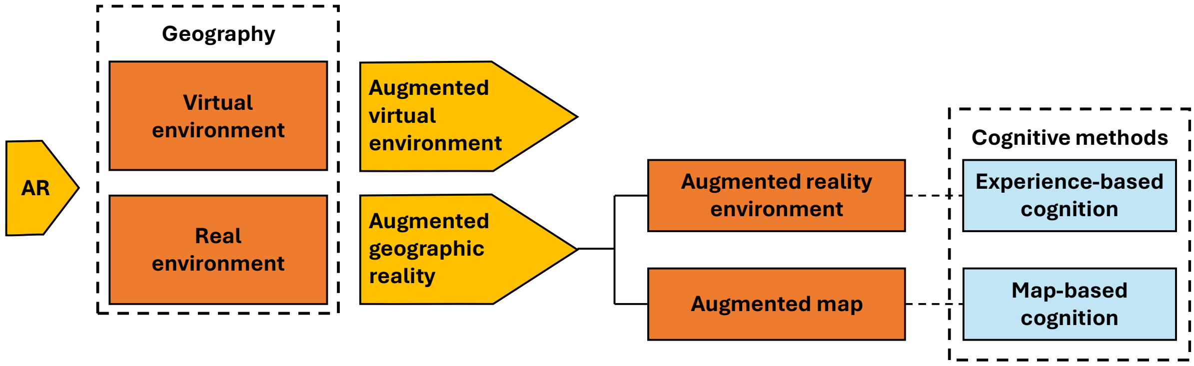


Figure 2.6 Combination of AR and geography (adapted from Cheng et al., 2022)

Most AR development in cartography is focused on ARE visualisations, with the majority of applications developed for education (Lampropoulos et al., 2022; Lindner et al., 2021; Simon, 2023; Turan et al., 2018; Yonov, 2019), navigation (Lakehal et al., 2023; Liu et al., 2021; Thi Minh Tran and Parker, 2020; Yonov and Petkov, 2020), geovisualisation (Cheliotis et al., 2021; Danado et al., 2005; Hruby et al., 2021; Liarokapis et al., 2005; Olberding and Vetter, 2023), tourism (Cibilić et al., 2021; El Choubassi et al., 2010; Häkkilä et al., 2016; Han et al., 2018; Sasaki and Yamamoto, 2019) and urban planning (Cibilić et al., 2024; Pavelka and Landa, 2024; Stylianidis et al., 2020; Wolf et al., 2020).

2.2.1 Augmented reality environments (ARE) for navigation

AREs in cartography have been examined from multiple perspectives, with foundational questions focusing on how to integrate cartographic principles into AR systems. As Bednarczyk (2017) emphasised, semi-virtual cartographic environments can function as legitimate digital cartographic tools only when cartographic laws, rules, and knowledge are fully integrated. This principle has motivated research into adapting traditional cartographic design for AR contexts. Halik (2012) analysed visual variables specifically for mobile AR point symbols, while Dickmann et al. (2021) examined more broadly how AR techniques impact cartographic visualisation. Closely related to these considerations is cognitive load – a critical factor determining whether AR systems support or hinder user performance. Buchner et al. (2021) conducted a systematic review concluding that AR can reduce cognitive load and assist task completion, while Amorim and Schmidt (2021) stressed that creating effective AR cartographic experiences requires particularly conscious design choices grounded in established cartographic principles.

These theoretical concerns take concrete form in application domains, particularly tourism and navigation. Tourism applications have explored how AREs can enrich visitor experiences through contextually relevant information overlays. Häkkilä et al. (2016) investigated projected fiducial markers for guided tours, Poslončec-Petrić et al. (2023) examined AR for presenting archaeological content, and Hedley (2017) provided broader perspectives on AR in tourism contexts, collectively demonstrating AREs' capacity to enhance cultural heritage experiences by seamlessly blending digital information with physical environments.

However, most ARE research in cartography focuses on navigation, reflecting practical demands for wayfinding support (Cheliotis et al., 2023). Early work by Goldiez et al. (2007) examined the effects of AR display settings on wayfinding performance, while Dünser et al. (2012) explored handheld AR for outdoor navigation. More recent comparative studies have expanded this foundation: Dong et al. (2021) contrasted AR with traditional 2D electronic maps in pedestrian wayfinding, and Lakehal et al. (2023) compared spatial knowledge acquisition between smartphones and AR glasses, with both studies indicating no significant differences between ARE visualisations and mobile map usage. Nevertheless, these studies demonstrate AR's effectiveness in guiding users to destinations efficiently.

Despite demonstrated effectiveness in immediate wayfinding, ARE navigation systems face a critical challenge regarding spatial knowledge acquisition – the ability of users to build mental representations of environments and navigate independently in the future. As Ruginski et al. (2019) stated, users tend to follow navigation instructions passively without actively engaging with their surroundings, which could impair route memory and hinder spatial knowledge acquisition. This passive reliance on technology creates a dependency that undermines the very purpose of navigation aids: to help users understand and navigate spaces independently. Users accustomed to AR navigation may struggle to recall routes when technology fails or is unavailable, potentially compromising safety in unfamiliar or challenging environments. Studies by Liu et al. (2021) and Keil et al. (2020) have reinforced this concern, documenting measurable deficits in spatial memory formation when users rely on AR navigation compared to traditional map-based navigation. This paradox – that navigation aids excel at immediate wayfinding but may undermine long-term spatial understanding – represents a significant challenge that current approaches have not adequately addressed. These findings represent a challenge within the current mobile maps context (Hejtmánek et al., 2018; Toru Ishikawa et al., 2008; Ruginski et al., 2019), as well as in ARE visualisations (Keil et al., 2020; Rehman and Cao, 2017; Yount et al., 2022).

This spatial learning limitation highlights significant gaps in current AR cartography research. Most ARE applications prioritise immediate task completion over spatial knowledge development, reflecting a technology-driven approach. This research addresses these gaps by focusing on AMs rather than AREs. Unlike ARE navigation systems, which overlay directional instructions on real-world views, AMs enhance traditional map representations – interfaces already optimised for spatial cognition and learning. Learning about space from a map differs from learning about space from navigation. When navigating, our position and viewpoint relative to the scene are constantly changing. In contrast, a map offers a stable view in which large areas can be examined at a glance (Uttal, 2000). Therefore, by augmenting maps rather than replacing them with direct environmental overlays, AMs have the potential to support both immediate wayfinding and long-term spatial knowledge acquisition (Ishikawa and Montello, 2006; Richardson et al., 1999; Thorndyke and Hayes-Roth, 1982; Uttal, 2000).

2.2.2 Augmented maps (AMs)

The first developed AMs were examined as collaborative tools (Bobrich and Otto, 2002), leading to the emergence of the mobile AM concept (Reilly et al., 2006; Reitmayr et al., 2005; Schöning et al., 2006). Reitmayr et al. (2005) developed a system that augmented printed maps with projector-based overlays and tangible user interfaces, allowing multiple users to interact with dynamic digital content on physical maps. Reilly et al. (2006) combined traditional paper maps with electronic information accessed via RFID-enabled handheld devices, enabling users to retrieve location-specific digital data by waving the device over map regions. Their evaluations showed that the AM approach was promising for tourism and mobile access to location-based information, offering ease of use and preserving the familiarity of paper maps. It should be noted that they utilised a technology that is no longer in use. Schöning et al. (2006) proposed using mobile camera devices as "magic lenses" to augment physical maps by overlaying dynamic georeferenced content. They addressed challenges such as marker occlusion and reliable tracking. Although their research was technology-oriented, it represented an important step towards user-friendly mobile AM interactions. Building on these advances, Morrison et al. (2009) introduced MapLens, the first mobile AM system based on map features. Their research demonstrated that AMs could support collaboration more effectively than traditional electronic maps, even outside controlled laboratory settings. Later, Morrison et al. (2011) concluded that any map could serve as a platform for mobile, location-aware applications.

From a software design perspective, progress in AM research has closely followed broader technological advancements. Adithya et al. (2010) proposed a novel AM rendering and interaction method that incorporated multiple markers, while Paelke and Sester (2009) integrated paper maps with functions such as positioning and real-time updates using specialised transparent devices. Other researchers, including Asai et al. (2008) and Chatain et al. (2015), investigated alternative input modalities for AMs. Bednarczyk (2017) further enhanced interactivity by creating an analogue map connected to an external database, similar to GIS systems. These studies have made substantial contributions to integrating AR technology with maps. However, most of these approaches were experimental prototypes developed independently within academic contexts, which limited their practical deployment. This limitation likely resulted from the immaturity and technical complexity of the technology at the time. More recently, Zou et al. (2023) advanced the field by exploring automatic generation of AM prefabs (Unity object templates for map point symbols) using object detection models, producing a stable and accurate prototype aligned with current technological capabilities.

These foundational advances have paved the way for AM applications in diverse domains, with tourism emerging as a high-potential area (Norrie and Signer, 2005; Stroila et al., 2011; Besharat et al., 2016; Wüest and Nebiker, 2018). Norrie and Signer (2005) used Anoto technology for high-resolution positioning of augmented paper maps with tourist information, with a user study showing positive results. Stroila et al. (2011) demonstrated an AR navigation application that allowed users to interact with transit maps in public transit locations and vehicles. However, the authors did not conduct a user evaluation of the application. Besharat et al. (2016) evaluated the visualisation of different points of interest (POIs) from a collaborative perspective with tourists, and their findings showed that navigation tasks could be completed successfully, though without significant performance gains over traditional maps. Wüest and Nebiker (2018) augmented large-scale walkable maps and orthoimages in museums with dynamic 3D data such as live air traffic and weather conditions.

However, these projects often overlooked cartographic principles and typically used maps mainly as markers to trigger augmentations. This approach is similar to adding selected elements onto an image base map for orientation, where most spatial information remains unchanged. De Almeida Pereira et al. (2017) were among the first to assess AR's contribution to map reading and spatial understanding, noting improvements in spatial positioning through virtual overlays. However, their prototype treated the virtual content as a single overlay rather than as an integrated extension of the analogue map. In summary, research on AM theory in cartography remains limited.

2.2.3 Why augmented maps need cartography

Most AM research to date has been technology-driven, and this focus is well justified; functioning technology plays an important role in any AR experience (Çöltekin et al., 2020; Werner, 2018). Unlike traditional graphical interfaces for desktop systems, AR interfaces must address unique technical challenges of mobile displays, such as limited screen size, unreliable connectivity, short battery life, and contextual factors like weather and lighting conditions (Çöltekin et al., 2020). Furthermore, AR combines physical real-world information with virtual content, creating new interface dynamics that challenge established cartographic design principles. Despite the successful deployment of AR systems, there is still limited knowledge of how content and graphical design decisions influence user effectiveness and efficiency (Anastopoulou et al., 2023). This knowledge gap primarily results from an incomplete understanding of the user requirements necessary for efficient and effective interaction with AR in general, and AMs in particular. Without this understanding, the development of practical design methodologies for conveying spatial information from a cartographic perspective remains constrained. Addressing these challenges requires a shift towards user-oriented design approaches that prioritise understanding and meeting user needs in AM systems.

2.3 User-centred design (UCD) for map design

2.3.1 Usability and UCD foundations

Technological advances in the second half of the 20th century profoundly shaped computing and information systems. When computers were used only by a small number of specialised users, it was logical to require a high degree of learning and expertise to use them efficiently (Lazar et al., 2017). Over time, the democratisation of personal computers – and later mobile devices – enabled their use for a wider variety of tasks by an increasingly diverse population. Researchers recognised that a shift from technology-centric to human-centric approaches was necessary, leading to the development of human-computer interaction (HCI) research (Lazar et al., 2017). Early work focused on ergonomics and interface design principles to serve users as tools for achieving their goals (Lazar et al., 2017; Norman, 2013; Rubin et al., 2008). This created the need for systematic methods to define, measure, and achieve usability in design practice, and to integrate user understanding into development through structured, measurable processes (Gould and Lewis, 1985; Norman and Draper, 1986). Among the most influential approaches was a structured framework introduced in the early 1990s by Jakob Nielsen. In his book Usability Engineering (Nielsen, 1993), he defined usability through five measurable attributes:

- learnability (how easy it is for users to accomplish basic tasks the first time they encounter the design),
- efficiency (once users have learned the design, how quickly they can perform tasks),
- memorability (when users return to the design after a period of not using it, how easily they can reestablish proficiency),
- errors (how many errors users make, how severe these errors are, and how easily users can recover from them) and
- satisfaction (how pleasant it is to use the design).

Nielsen positioned these attributes within a broader framework of system acceptability, distinguishing between usability (ease of use, i.e., how well users can use the functionality) and utility (whether the system provides the needed functionality). This approach treated usability primarily as a set of product properties – interface characteristics that could be identified and evaluated during design and serve as a measurable attribute of user acceptance.

Researchers such as Nigel Bevan and Miles MacLeod advocated understanding usability as "quality in use" – the outcome when users interact with a product in specific contexts (Bevan, 1995; Bevan and MacLeod, 1994; Maguire, 2001). Their work within the MUSiC research led to the development of standardised tools and methods for measuring three high-level outcomes: effectiveness, efficiency, and satisfaction (Bevan, 1995). They recognised that Nielsen's five attributes could be derived from or measured within these three fundamental constructs (Bevan and MacLeod, 1994): learnability can be seen as a temporal measurement of effectiveness and efficiency manifested as change over time or across experience levels, memorability can represent effectiveness and efficiency after periods of non-use (a temporal variation), while errors contribute directly to effectiveness (goal achievement) and efficiency measures (time or effort to recover). Their work was supported by the definition of usability as "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Bevan et al., 2016; International Organization for Standardization, 2018), where effectiveness is defined as the accuracy and completeness with which users achieve specified goals, efficiency addresses resources used in relation to the results achieved (i.e. time, human effort, costs and materials), and satisfaction focuses on users' physical, cognitive and emotional responses (i.e. attitude and comfort) resulting from the use of a system or product (ISO 9241-11:2018; Vanicek and Popelka, 2023).

Building on the formal definition of usability, User-Centred Design (UCD) has emerged as a holistic and iterative methodology for applying usability principles throughout the entire design and development process (Nielsen, 1993; Norman, 2013). Rather than viewing usability solely as a product attribute measured after design completion, UCD promotes continuous user involvement to ensure that design decisions consistently reflect actual user needs, tasks, and contextual constraints (Norman and Draper, 1986; Norman, 2013). This process aligns with ISO (9241-210:2019), which structures UCD principles into four key activities: analysing the context of use, specifying user requirements, producing design solutions, and evaluating designs through user-based assessment. By iteratively integrating user feedback, UCD reduces design risk and increases the likelihood of delivering systems that are not only usable and useful but also acceptable in practice. This approach yields benefits recognised across the product life cycle, including higher productivity and operational efficiency, lower training and support costs, greater accessibility and user well-being, improved user experience, and contributions to sustainability (ISO 9241-220:2019).

While user-oriented design is a relatively recent addition to cartographic vocabulary, scholars had already begun investigating how users perceive and understand maps. During the 1970s and 1980s, academic cartographers, often collaborating with cognitive psychologists, studied map symbol recognition, colour perception, and reading efficiency (Roth, 2019). This foundational work established the scientific basis for understanding human map interpretation before structured UCD methodologies became commonplace in the discipline.

2.3.2 UCD in cartography

By the beginning of the 21st century, research showed the recognition of UCD methods in cartographic research. For example, Monmonier and Gluck (1994) conducted focus groups to gather user feedback on dynamic cartography prototypes, using qualitative insights to refine design decisions. This is an early instance of a formal user-oriented approach: rather than relying solely on the cartographer’s intuition, the design was iteratively improved based on empirical feedback about what users found confusing or useful. Similarly, Kessler (2000) used focus groups to evaluate thematic map narratives for user comprehensibility, while Harrower et al. (2000) incorporated formal user testing into their educational geographic visualisation tool. These early map use studies, while not always explicitly labelled as UCD, laid the groundwork by treating the map user as an important element in design.

However, the advent of digital, interactive, and later mobile mapping truly catalysed the adoption of formal UCD practices in cartography (Fuhrmann et al., 2005; Ooms et al., 2015; Roth and Harrower, 2008; Slocum et al., 2001). Slocum et al. (2003), for instance, conducted a qualitative usability evaluation of a spatiotemporal visualisation tool by observing how users interacted with it to identify design shortcomings. Haklay and Tobón (2003) demonstrated that public participation in GIS interface design yielded meaningful results when user feedback was prioritised. Robinson et al. (2005) combined multiple usability techniques to develop epidemiological geovisualisation tools tailored to domain-specific user needs.

Recognition of usability principles prompted cartographers and GIScience researchers to systematise UCD into explicit, iterative frameworks. Multiple scholars within GIScience have formalized UCD into a set of iterative stages (Fuhrmann and Pike, 2005; Gabbard et al., 1999; Howard and MacEachren, 1996; Robinson et al., 2005; Roth et al., 2015; Roth et al., 2010; Slocum et al., 2003; Tsou and Curran, 2008).

Gabbard, Hix, and colleagues (Bowman et al., 2002; J.L. Gabbard et al., 1999; Hix et al., 1999) outlined a four-stage process, beginning with (1) user task analysis (i.e., needs assessment), followed by progressing through (2) guidelines-based evaluation on early prototypes (using Nielsen's guidelines and heuristics), (3) formative evaluation on an early release, and (4) summative comparative evaluation on the full release. Slocum et al. (2003) expand this to six stages, making the evaluation-refinement coupling explicit: (1) creation of a prototype, (2) domain expert evaluation, (3) software refinement, (4) usability expert evaluation, (5) additional software refinement, and (6) decision maker (i.e., target user) evaluation. Interestingly, Slocum et al. (2003) include steps for gathering input from both experts and target users, as in other UCD processes, but do not begin design and development by seeking user input in a needs assessment study, unlike other UCD processes, instead starting with rapid prototyping.

Tsou and Curran (2008) adapt Garrett's (2002) five-stage user experience framework to web mapping, describing five different design "planes" that can be evaluated and refined by target users before implementation: (1) strategy plane (general user needs supported by the interface), (2) scope plane (specific mapping objectives supported by the interface), (3) structure plane (enumeration and organisation of interface requirements), (4) skeleton plane (low-fidelity prototype sketching the interface layout), and (5) surface plane (high-fidelity prototype illustrating the final product identity of the interface).

Notably, Robinson et al. (2005) describe a UCD process that emphasises the highly iterative nature of UCD, encapsulating multiple user→utility→usability loops within a recursive six-stage process (Figure 2.7a): (1) work domain analysis, (2) conceptual development, (3) prototyping, (4) interaction and usability studies, (5) implementation, and (6) debugging. This model positions a needs assessment at the outset, establishing utility baselines against which usability is optimised through multiple user feedback cycles.

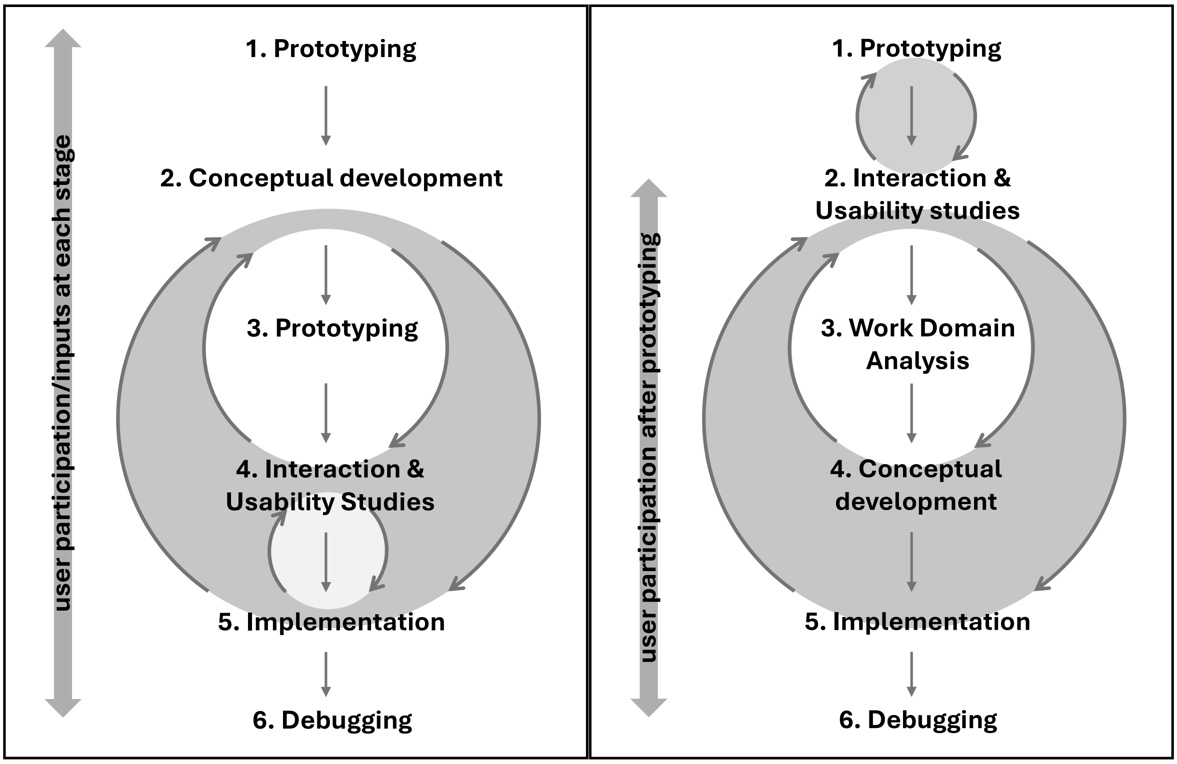


Figure 2.7 a) Robinson et al.'s (2005) six-stage user-centred design process and b) Roth et al.'s (2010) modified user-centred design approach

Roth et al. (2010) modified the Robinson et al. (2005) framework by strategically inverting the sequence: (1) prototyping becomes the initial step, preceding formal conceptual development. Rather than beginning with needs assessment, features are iteratively added to the prototype as design possibilities emerge. (2) Early formative evaluation stabilises the prototype sufficiently for user demonstration, after which it is reintroduced as part of the (3) work domain analysis to elicit user insights and reactions unlikely to surface through traditional needs assessment alone. This dual feedback pathway – combining insights from rapid prototyping with structured analysis – informs (4) the conceptualisation of the fully featured application. (5) Subsequent iterations cycle through interface implementation, interaction and usability studies, and conceptual refinement, ultimately concluding with (6) a debugging stage (Figure 2.7b).

2.3.3 UCD evaluation methods

However, these UCD processes typically do not identify the actual method used for evaluating the interface. A wide variety of methods have been suggested for interface evaluation, with extended discussion of particular methods for cartographic research (Çöltekin et al., 2008; Fuhrmann and Pike, 2005; Haklay and Nivala, 2010; Haklay and Zafiri, 2008; Marsh and Haklay, 2010; Ooms et al., 2015; Robinson et al., 2011).

For example, Buttenfield (1999) categorised evaluation methods by design phase: (1) design-stage methods include participant observation and needs interviews; (2) development-stage methods encompass cognitive walkthroughs and conformity assessments; and (3) deployment-stage methods include automated evaluation and user surveys. Bowman et al. (2002) proposed six decision criteria for method selection: (1) evaluation goals, (2) timing within the UCD process, (3) contextual applicability, (4) costs, (5) benefits, and (6) intended use of results. Roth and Harrower (2008) synthesised this diversity through a methodological continuum spanning from quantitative approaches (designed to generate summary statistics concerning the influence of an independent variable on the usability of an application) to qualitative methods (Figure 2.8). It is important to note that several methods along the centre of the continuum can generate both quantitative and qualitative data. The continuum also reflects transitions in sample size (large to small) and research objectives (universal guidelines to single-application refinement). Results from usability testing can still inform design decisions on other projects, but not with the same degree of predictability as controlled experimentation. Finally, the continuum also represents a shift from summative evaluation to formative evaluation. The purpose of summative evaluation is to provide an overall ranking on aspects of usability after construction is completed, allowing for direct comparison with similar applications. In contrast, the purpose of formative evaluation is to ensure that interface prototypes are meeting users' needs and expectations. In formative evaluation, both usability (i.e., how easy it is to use) and utility (i.e., how useful it is) are evaluated (Roth and Harrower, 2008). Formative evaluation is administered multiple times throughout the development process, improving the prototype iteratively (Fuhrmann et al., 2005; Krug, 2014). Roth et al. (2015) added another organising principle: discriminating evaluation methods by evaluator type (expert-based, theory-based, user-based), with each suitable for different contexts. User-based evaluation remains the cardinal characteristic, with expert and theoretical insights positioned as supplements to target user feedback rather than replacements.

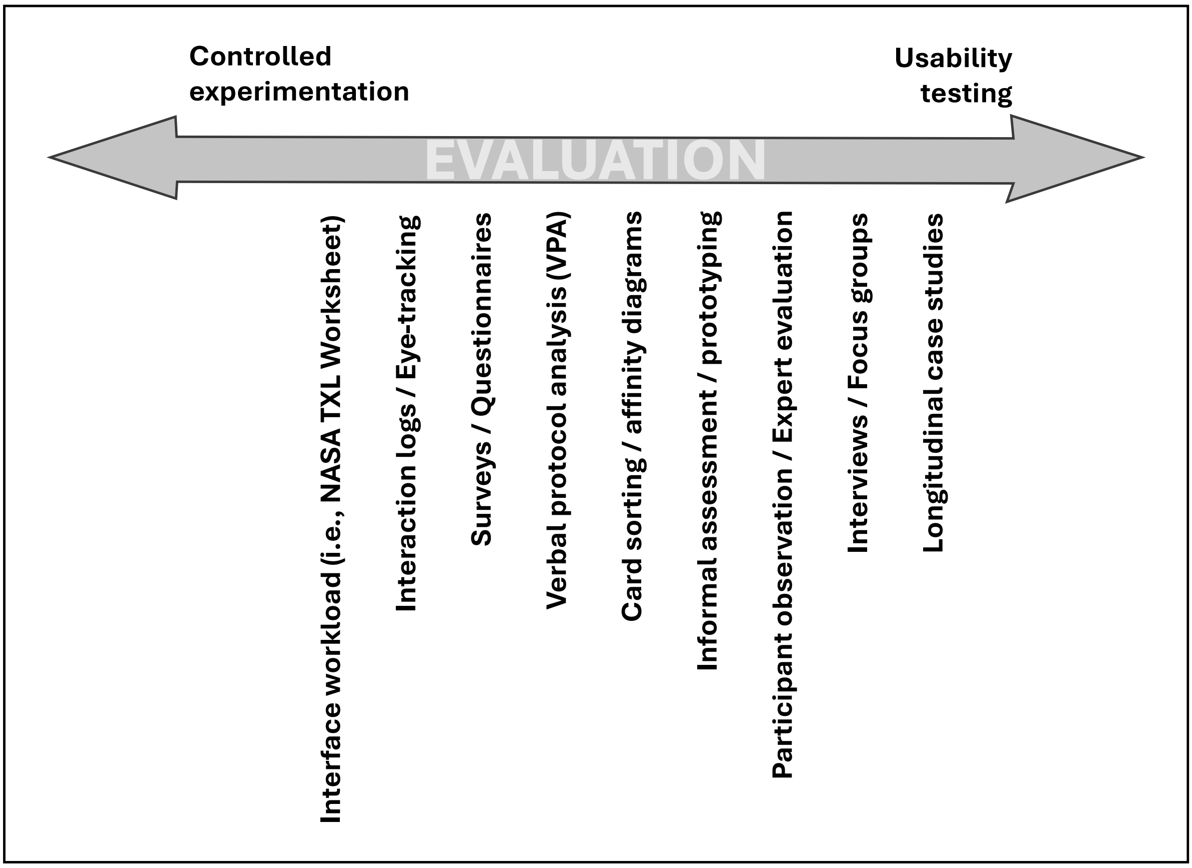


Figure 2.8 A continuum of evaluation methods from cartographic perspective (adapted from Roth and Harrower, 2008)

Smartphones and mobile mapping applications introduced unique usability challenges: small screens, touch interfaces, variable lighting and outdoor conditions, GPS-enabled context awareness, and diverse user demographics. Designing effective mobile maps required a deeper understanding of user context – the circumstances in which the user interacts with the map and their environment. Researchers focused on context-aware (Bartling et al., 2022; Griffin et al., 2017; Sarjakoski and Nivala, 2005) and adaptive cartographic design (Jenny, 2012; Konečný and Staněk, 2010; Reichenbacher, 2001, 2003, 2004; Reichenbacher and Bartling, 2023), enabling users to customise the mapping system according to their abilities and preferences, while allowing devices to adapt to environmental and contextual changes. Extending UCD to account for everything from the user's physical environment and device to their cognitive state and goals represents a maturation of UCD in geospatial technology and cartography.

Contemporary cartography has consolidated around user-oriented practices for designing and assessing interactive maps and visualisations (Bergmann Martins et al., 2023; Griffin et al., 2024; MacEachren and Kraak, 2001; Robinson et al., 2023; Roth, 2015, 2019; Roth, Çöltekin, et al., 2024; Roth, Griffin, et al., 2024; Vanicek and Popelka, 2023). Roth et al. (2017) identified cross-cutting methodological opportunities, emphasising rigorous UCD study design for interaction design, serving general audiences where interactive maps function as communication, personalisation, and entertainment media. Roth (2019) articulated the broader intellectual contributions of UCD research, demonstrating that user studies enrich cartographic knowledge in multiple ways. UCD investigations identify domain-specific gaps in existing applications, revealing unmet user needs within specific domains. As these methods mature, they produce transferable design principles – practical, evidence-based guidelines that mapmakers can rely on – while comprehensive case studies teach others how to conduct user research thoughtfully. Meaningful collaboration with users generates novel cartographic solutions that designers alone would not have imagined, and rigorous testing produces experimental evidence showing concretely how different design choices affect users' performance and understanding of maps. Beyond this, UCD studies offer theoretical insights that deepen cartographic understanding of how people conceptualise distance, uncertainty, or temporal change.

This framework reframes user-oriented research as legitimate cartographic science rather than isolated design exercises or procedural boxes to check. User studies simultaneously advance both disciplinary theory and practice – understanding how users interpret animated versus static maps contributes to both design guidance and fundamental cartographic knowledge. Contemporary cartography thus recognises UCD research as generalisable science, establishing user study findings as credible theoretical contributions.

2.3.4 UCD within AR and tourism

As AR technology evolves from a novelty to practical applications, researchers have recognised that technical innovation alone is insufficient; AR interfaces must also be intuitive, efficient, and satisfying to use. AR interfaces differ from traditional desktop or mobile screens because they merge physical and digital elements and introduce new interaction paradigms, creating distinctive usability challenges (Dünser et al., 2007). In addition to small screens and divided attention on smartphones, AR systems must also address restricted fields of view in head-worn displays, high demands on tracking and battery, and non-traditional input modalities such as gestures, gaze or voice, which may be challenging in real-world environments (Derby and Chaparro, 2021; Kruijff et al., 2010), making thoughtful design essential. Given these challenges, a UCD approach is important to ensure AR systems are effective and intuitive in everyday conditions. When considering design guidelines for AR, it is also useful to draw insights from the VR literature, as it has traditionally devoted more attention to HCI integration (Bowman et al., 2002). Because VR and other XR systems share several interface and interaction characteristics, some principles can be transferred; however, important differences remain, and any guidance must be carefully adapted to the specific constraints and requirements of AR systems (Krauß et al., 2021).

Several studies highlight the advantages of UCD alongside existing shortcomings. In the tourism domain, Hammady et al. (2018) and Han et al. (2018) examined user experience in urban heritage AR applications in museums and noted that the emotional and experiential impacts of AR content require further user-oriented investigation (Han et al., 2018). Similarly, Olsson et al. (2012) conducted an early user evaluation of mobile AR scenarios (including navigation and sightseeing contexts) via surveys, finding that users were intrigued by AR's possibilities but also concerned about usability issues and certain technological risks (e.g. distractions, privacy), emphasising the importance of design that prioritises user concerns.

For tourist maps, prior research emphasises that the learning curve should be as short as possible, which is why intuitive visual symbols play such an important role. Pictograms are particularly suitable for novice and occasional users because they can often be interpreted correctly without prior learning or consulting a legend, and are among the most effective forms of non-linguistic information (Halik and Medyńska-Gulij, 2017; Sasaki and Yamamoto, 2019). In AR sightseeing systems, this advantage becomes even more critical, as legends and long labels are difficult to accommodate in a limited and constantly changing field of view. Sasaki and Yamamoto's (2019) sightseeing AR system in Japan, for example, used universally recognisable pictograms to represent attractions, which improved usability for international users. Such findings require careful design considerations because, from a UCD perspective, the important component is not only symbol choice but also symbol behaviour: where to place pictograms in the augmented scene, at what size, and how to avoid cluttering or occluding the scene. These parameters are difficult to derive from cartographic theory alone and therefore need to be refined through iterative user testing.

As outlined in the previous subsection on ARE navigation, empirical studies show that AR route guidance can improve immediate wayfinding but does not automatically enhance spatial knowledge acquisition and may even encourage overly passive navigation behaviour (Dong et al., 2021; Huang et al., 2012; Ruginski et al., 2019). From a UCD standpoint, this finding implies that AR navigation aids should be evaluated not only for short-term efficiency, but also for how they influence users' engagement with the environment.

There have been moves towards more structured UCD methodologies for AR in recent years (Choong et al., 2022; Dünser et al., 2008; Endsley et al., 2017; Gabbard and Swan, 2008; Graser et al., 2024; Irshad and Awang, 2018; Krauß et al., 2021; Labrie and Cheng, 2020; Merino et al., 2020; Vi et al., 2019). Early surveys by Dünser et al. (2008) and Gabbard and Swan (2008) documented that most AR studies lacked formal user evaluation and argued that user-based studies should iteratively inform design. Irshad and colleagues (Irshad et al., 2020; Irshad and Awang, 2018; Irshad and Rambli, 2015) proposed user experience frameworks and evaluation models tailored to mobile AR that combine instrumental (e.g. efficiency, dependability) and non-instrumental (e.g. aesthetics, stimulation, novelty) quality attributes for mobile AR applications. More recently, Endsley et al. (2017) derived nine heuristics for AR design from a broad set of statements in AR and related fields. Vi et al. (2019) later expanded on this work by proposing design guidelines for XR displays, focusing mainly on head-mounted displays and VR. Labrie and Cheng (2020) extended classical usability heuristics into an initial set of AR-specific design guidelines – an important step towards UCD in AR, as these guidelines were derived from examining real AR applications and usability issues. Choong et al. (2022) developed an AR usability evaluation framework that outlines a systematic process for user-based testing of AR systems. Their framework emphasises defining the evaluation scope, identifying target users and contexts of use, designing realistic tasks, and selecting appropriate usability metrics. Despite these advances, UCD in AR remains at an early stage (Krauß et al., 2021; Labrie and Cheng, 2020). A recent systematic review by Graser et al. (2024) confirms that most AR evaluations to date have been quantitative and technology - focused. Their review identified only a few AR-specific frameworks and noted a lack of standardised metrics.

These findings are particularly relevant to the evolution of AMs. The earlier review of AM prototypes (e.g., Bobrich and Otto, 2002; A. Morrison et al., 2009; Reilly et al., 2006; Schöning et al., 2006) showed that most developments have been technology-driven, with limited systematic involvement of end-users. Recent work emphasises that such visualisations should adhere to established design rules and symbolisation principles (Amorim and Schmidt, 2021; Bednarczyk, 2017; Cheng et al., 2022), but very few studies translate these insights into robust, repeatable, user-oriented design and evaluation processes for AMs. The absence of such a framework means that much AR work in general, and AM projects in particular, rely on ad hoc design choices or borrowed principles, which may not be applicable in these settings. Çöltekin et al. (2020a, 2020b) emphasise that AR's blending of physical and digital information "questions the applicability of established cartographic design principles," and there is still much to learn about what AR map users need for effective, efficient, and satisfying use. Thus, despite promising prototypes, UCD for AMs remains underdeveloped – a gap this thesis addresses by applying a UCD approach to the design and evaluation of tourist AMs.

2.4 Chapter summary

This chapter presents tourist maps as communication tools whose effectiveness depends not only on the cartographer's intentions, but also on how people actually read and understand cartographic content. It also demonstrates why mobile and AR contexts make map use more demanding: limited screen space, divided attention, and the blending of physical and virtual information can affect familiar map-reading routines. Within this context, the chapter emphasises the differences between AR environments that primarily support in-situ perception and navigation, and Ams, which extend map-based thinking by placing digital content directly onto a cartographic representation.

For this reason, this thesis treats map augmentation as a cartographic design decision that should be tested rather than assumed. The design proposition developed in the following chapters is that selected tourist information can be relocated from a printed base map to a virtual layer to reduce visual competition on the paper map while maintaining clarity and legibility. This proposal is developed and addressed through a user-oriented methodology, elaborated in the following chapter.

Against this background, the contribution of this thesis is twofold. First, it reframes map augmentation as a cartographic strategy of layer allocation, where thematic information is deliberately distributed between a printed and a virtual layer to manage visual competition while maintaining legibility. Second, it contributes methodologically by translating this concept into an ISO-aligned, user-oriented methodology intended to be repeatable beyond a single prototype. This is demonstrated in the context of Croatian national park tourist maps, moving from symbol and user evidence to design decisions and controlled usability evaluation. Together, these contributions shift AMs from technology-led visualisations towards cartographically justified layer design and ISO-aligned user evaluation.

3 METHODOLOGY

3.1 Research Design and Approach

The main focus of contemporary cartography is understanding the processes and methods for effective communication of spatial information (Robinson et al., 2023), which depends largely on how relevant information is structured and cognitively processed (MacEachren, 1995). When considering cartographic applications within an emerging technological field such as AR, technological considerations must be aligned with cartographic communication principles. Building on the theoretical foundations from Chapter 2, this thesis developed and applied a UCD methodology for the design and evaluation of the AMs by integrating cartographic principles with usability engineering practices (Figure 3.1).

Although ISO (9241-210:2019) provides a general structure for user-oriented design, it does not specify how these activities should be operationalised for AMs, where cartographic communication constraints and AR interaction design must be addressed together. The methodological contribution of this thesis is therefore the five-phase workflow shown in Figure 3.1. It defines a repeatable sequence that moves from evidence to design and then to evaluation: from competitive analysis and user needs assessment, through controlled prototyping and expert review, to comparative user-based usability evaluation. By defining the intended inputs, outputs, and iteration points for each phase, the methodology is intended to be applicable beyond the present case study while remaining grounded in cartographic principles and usability outcomes.

As mentioned, the methodology is structured into five-phases: competitive analysis, user needs assessment, conceptual design and AR prototyping, expert review, and user-based usability evaluation. The phases are introduced and described in detail in the following sections.

This research is considered user-oriented in two main ways. First, it treats potential users as a key source of input regarding which content, functionalities, and representations they find useful. Their needs are collected and interpreted before the AM design, rather than being considered only at the end of the development process. Second, this approach involves users and experts in several iterative feedback loops, with prototypes repeatedly refined based on empirical findings.

The proposed approach follows the ISO (9241-210:2019) structure of UCD principles with four key activities: analysing the context of use, specifying user requirements, producing design solutions, and evaluating designs through user-based assessment. A central feature of the research design is its emphasis on formative evaluation throughout the UCD cycle (Gabbard et al., 1999; Roth et al., 2017; Slocum et al., 2003). Formative evaluation is used to identify problems and opportunities for improvement during design and development, rather than only measuring final performance at the end. This approach is particularly important for emerging technologies such as AMs, where design conventions are not yet established and prototypes are expected to evolve.

The methodological approach explicitly integrates expert-based, theory-based and user-based evaluation methods, following contemporary recommendations in cartography UCD literature (Roth et al., 2015). Each perspective contributes distinct insights into the quality and usability of AMs. Theory-based evaluation is applied in the initial phase, during the analysis of existing maps. Theoretical frameworks also provide criteria for expert evaluation and layout decisions in the new AM prototype. Expert review offers detailed, domain-specific feedback on the correctness, consistency, and legibility of the design, as well as on the appropriateness of integrating AR elements into a cartographic representation. User-based evaluation is conducted during the needs assessment phase at the beginning of the process and again in the final usability study.

The number of participants required to provide meaningful input was determined separately for each phase, based on the purpose of each phase in the UCD cycle and the evaluation method used. HCI literature shows that sample size decisions are influenced by several factors, including the properties and complexity of the system, the stage in the usability lifecycle, whether the evaluation is formative or summative, and the representativeness of participants (Alroobaea and Mayhew, 2014). Larger samples generally increase the stability of findings but also raise the time and cost required for recruitment and analysis; therefore, usability research has long relied on models and rules of thumb for practical planning (Budiu and Moran, 2021; Hwang and Salvendy, 2010). However, “universal” numbers should be treated with caution, as they can underestimate the sample size needed under realistic conditions and heterogeneous user populations (Schmettow, 2012). In cartography, Bergmann Martins et al. (2023) similarly demonstrate that the appropriate number of participants varies with study purpose and method type, and their synthesis was used as a reference when selecting sample sizes across the phases of this research.

This research adopts a mixed-methods approach, combining qualitative and quantitative methods in a complementary way. Qualitative insights such as expert analysis, open-ended questions and think-aloud protocols, help interpret results and support the development of concrete cartographic recommendations and AR technology considerations. Quantitative measures, including task success, completion time, and standardised questionnaires, provide evidence for testing hypotheses about the usability of AMs.

Throughout the process, technological aspects of AMs are explicitly considered, including the target devices used for visualising the AM, the software platform for its implementation, and current recommendations for AR interface design (Dünser et al., 2007; Endsley et al., 2017; Krauß et al., 2021; Labrie and Cheng, 2020; Vi et al., 2019). These technological constraints guide decisions about the amount, form, and behaviour of content presented in the augmented interface.

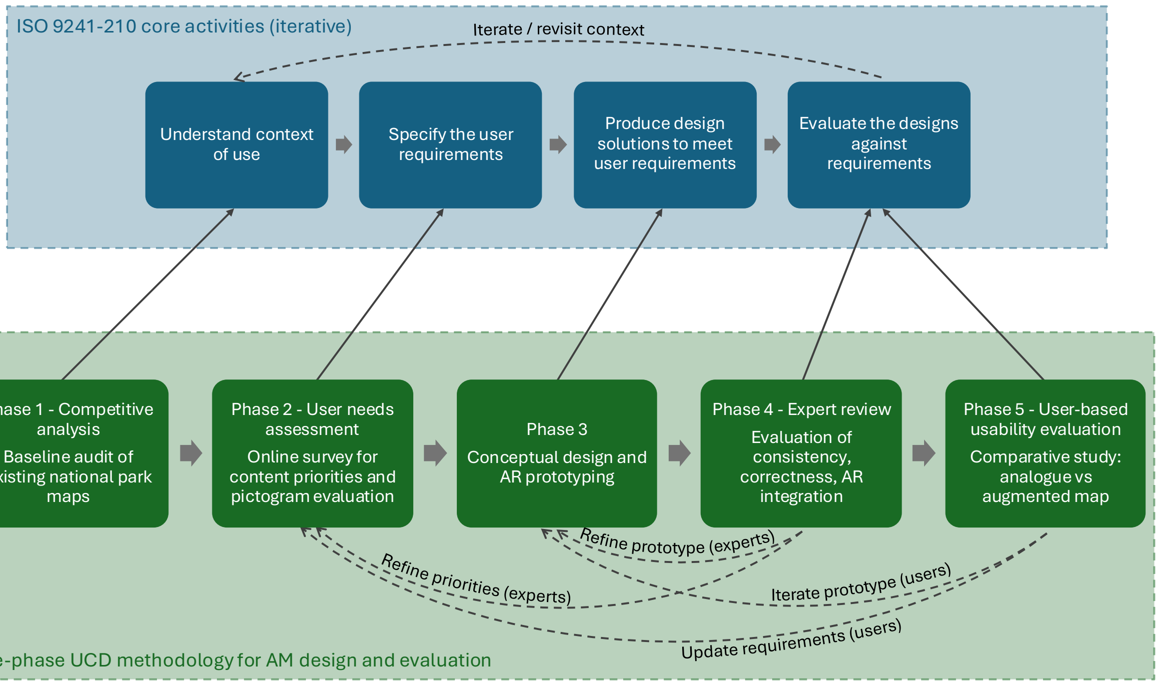


Figure 3.1 Proposed methodology for UCD approach for AM design. The upper row shows the ISO (9241-210:2019) core activities; the lower row presents the five phases used to operationalise these activities for AM design and evaluation. Solid arrows indicate the reported phase sequence; dashed arrows indicate iterative feedback loops

In following sections, this methodology is applied to a case study of Croatian national park tourist maps.

3.2 Study Context and Case Selection

3.2.1 Tourist maps as a medium

Tourist maps play a significant role in supporting tourism activities worldwide (Jancewicz and Borowicz, 2017). They are designed to help tourists organise their activities and access relevant information in unfamiliar locations (Özogul and Baran, 2016). Within cartography, tourist maps constitute a distinct and complex category, requiring special consideration of the principles and processes involved (McCleary, 2009). The design of tourist maps warrants scientific investigation due to the multiple factors involved, including the choice of scale, the appropriateness of cartographic symbols and text, the layout of graphical elements, and the representation of transport and tourism infrastructure (Airikka and Masoodian, 2019; Grant and Keller, 1999). A well-designed map enables tourists to discover attractions beyond the most popular sites, navigate unfamiliar spaces with ease (Han et al., 2018; Yan and Lee, 2015), and explore less-known areas, thereby contributing to the local economy (Eboy, 2017). On the other hand, poorly designed maps can cause confusion, leading tourists to miss important sites and activities (Jancewicz and Borowicz, 2017). As global travel trends increasingly emphasise the exploration of natural areas outside one's home country, such as national parks, the role of tourist maps in shaping these experiences has become even more significant (Taczanowska et al., 2019).

Contemporary visitors are constantly exposed to information and technological stimuli, yet many actively seek to spend more time in nature as a counterbalance (Korcz et al., 2024). In an increasingly competitive tourism industry, destinations are encouraged to adopt modern technologies to gain a marketing advantage (Han et al., 2013), and mobile tourism applications have become common tools for both trip planning and in-situ decision-making (Law et al., 2018). Research in nature-based tourism suggests that mobile technology can positively enhance travel experiences (Ghaderi et al., 2019).

As tourists are inclined to use mobile devices at tourist destinations, the potential of AR to enrich their experiences is increasing (Cabeleira and Vaz de Carvalho, 2025). However, new technologies introduce new forms of interaction and alter how users perceive map content, and the perceptual and cognitive effects of these changes are not yet fully understood. This is particularly relevant in tourist areas, where unclear information or visual overload can negatively influence visitor flows and affect sensitive, protected environments.

For these reasons, several authors emphasise the importance of incorporating user perspectives into the design of tourist maps. Empirical studies show that tourist input can be beneficial for map design (Zajadacz and Halik, 2024), and tourist maps should explicitly address user needs (Yung and Khoo-Lattimore, 2019). These findings align with the broader emphasis on a UCD approach in cartography (discussed in Chapter 2), and they provide the conceptual basis for this thesis. In summary, the creation of "tourist-friendly" maps requires investigation of user needs, interests, and preferences (Yan and Lee, 2015).

In the following subsection, this general context is narrowed to the specific case of Croatian national park tourist maps, which provide a coherent and realistic setting to operationalise and test the proposed methodology.

3.2.2 Case study: Croatian national parks

There are 444 protected areas in Croatia, covering 9% of the country (Croatian Ministry of Economy and Sustainable Development, n.d.). National parks are important public resources for conserving valued ecosystems and species (Bosworth and Curry, 2020). Croatian legislation defines them in Article 113 of the Law on Nature Protection (Official Gazette 80/13) as "... a vast, largely unaltered area of land and/or sea of exceptional and multiple natural values, including one or more preserved or slightly altered ecological systems, and primarily intended to preserve the original natural values".

Croatia has designated eight national parks: Plitvice Lakes, Krka, Sjeverni Velebit, Risnjak, Paklenica, Brijuni, Mljet, and Kornati (Figure 3.2). Each is managed by a separate public institution. These institutions form a unified group coordinated and funded by the Ministry of Economy and Sustainable Development, which provides central oversight and support.

Figure 3.2 Spatial distribution of Croatian National Parks

To enhance the recognisability of the nature protection system, the Ministry published the Ordinance on the Unique Visual Identity of Nature Conservation in the Republic of Croatia (Official Gazette 81/20). The Ordinance establishes a common visual identity and a system for interpreting and signposting protected areas in the Republic of Croatia (Ministry of Economy and Sustainable Development, 2020b), along with standards for their implementation and use (Ministry of Economy and Sustainable Development, 2020a). Although these guidelines are not mandatory for cartographic products, they serve as a useful reference for analysing the visual materials produced for national parks, including their degree of uniformity and their support for interpretation. Owing to this uniformity, Croatian national parks can be regarded as a group of tourist attractions that offer similar activities and produce cartographic products in the same way, for the same purposes.

In this context, Croatian national parks were selected as the case study for this thesis for several reasons. They represent a coherent group of tourist destinations with similar management structures, types of activities, and visitor profiles, making them suitable for comparative analysis. Additionally, these tourist maps share a unified visual identity, providing a consistent cartographic and graphic context for a meaningful analysis of design and communication differences. Croatian national parks are also similar in size, which is advantageous for comparison and analysis. They attract a large number of visitors throughout the year and play an important role in nature-based tourism in Croatia (Demonja et al., 2024), so any improvements in the usability and clarity of these maps provide direct benefits for both visitors and park authorities. Furthermore, Croatian national park maps are already available as established analogue products, while also offering realistic opportunities for mobile and AR-based extensions. This combination of coherence, practical importance, and technological potential makes them an appropriate case study for applying and testing the user-oriented methodology for AMs developed in this thesis.

3.3 Overview of Research Phases

This thesis proposes and implements a five-phase methodology that translates general UCD principles into a concrete research process for AMs, applied here to Croatian national park tourist maps. Each phase builds on the previous one, generating findings or design decisions that inform the next phase, while formative feedback loops allow refinement before the final usability evaluation.

In the following sections, each phase is described in detail, including the specific procedures, participants, instruments and analysis methods used in this thesis.

3.4 Phase 1 – Competitive analysis of existing maps

The initial phase involved a detailed expert cartographic analysis of existing tourist maps, with particular focus on analogue cartographic representations of national parks in the Republic of Croatia. These maps, provided by the relevant institutions, formed the basis for analysing current practices and identifying opportunities for improvement. Analysing existing products before involving users is a valuable preparatory step for needs assessment and can reveal new approaches to map design (Roth, 2019). This analysis was guided by established cartographic principles and communication strategies. The aim was to identify strengths and weaknesses in current practices, with emphasis on content selection, symbolisation, generalisation, and layout. The analysis also considered the unique visual identity of protected areas in Croatia. A detailed description of this phase is provided in Cibilić and Poslončec-Petrić (2025).

3.4.1 Study design

The analysed maps included both general and tourist maps provided by national park organisations. They formed a representative sample of maps used to provide tourist information about the national parks in Croatia. However, it is important to note that these maps are communication materials created primarily for informational purposes by national park institutions, and they vary in cartographic standardisation and metadata completeness. The maps were obtained by contacting each institution via email and telephone. Data collection took place in July 2024, when the tourist season was already underway, institutional services were operating at full capacity, and their products were prepared for distribution, including any seasonal updates or modifications. The institutions were asked to provide any analogue cartographic product, in printed or digital form. All provided data digitally, and several also sent their analogue products by post (Mljet, Paklenica, and Plitvice Lakes). Table 3.1 summarises the total number of maps, brochures, or other publications received from the institutions. Some items were excluded from analysis because (a) they were not published by the institutions, or (b) they lacked cartographic visualisation of the area.

Table 3.1 Distribution of cartographic products provided by the national park institutions

	NP Brijuni	NP Kornati	NP Mljet	NP Paklenica	NP Risnjak	NP Sjeverni Velebit	NP Krka	NP Plitvice Lakes
Maps	4	1	4	16	2	6	3	15
Flyers and brochures	11	1	2	2	0	0	2	3

As the format and number of provided cartographic products varied, the analysis and comparison were conducted using one map per park. Selecting a single map for each park was not an easy task. The selection criteria were: (a) maps with sufficient resolution for detailed inspection, (b) coverage of the entire park area, (c) publication by the national park institution, (d) the most recent publication, and (e) display in large format at the park entrance. The last criterion was verified through direct communication with park institution staff during the map collection process. The reason for this exclusion was clear: these maps were considered the most representative cartographic visualisations of each area. Not all provided maps met these criteria. For example, Paklenica National Park provided several JPG images that were unreadable due to poor resolution. Many were also part of the institution's management plan rather than tourist products. Such maps were excluded because their purpose was administrative rather than touristic.

3.4.2 Evaluation criteria

In total, eight maps (one per national park) were selected for detailed analysis. After map selection, the chosen maps were reviewed according to cartographic design guidelines. The evaluation followed the Map Evaluation guidelines (Esri Mapping Center, 2007) and Frangeš et al. (2019), and the analytical framework was based on Frangeš (2012, 2013). The analysis was qualitative and descriptive, focusing on how cartographic decisions support or hinder tourist map use. The elements of cartographic content covered by the analysis are summarised and presented in Chapter 4. Maps included in the analysis are available in Appendix A, together with a detailed written analysis for each map.

The analysis considered basic map elements: title, represented area and orientation, content, scale, projection information, map format, legend, map graphics, author (producer) and production date, publisher and circulation, data sources, and other relevant map elements. Although pictograms are an important component of tourist maps, a detailed comparative analysis of individual symbols was not carried out at this stage because the symbol sets differed substantially between parks and were not uniform. Instead, pictograms were examined as part of the overall cartographic design, and the selected maps were evaluated as comprehensive products rather than by isolating specific elements. This approach ensured that the initial evaluation focused on the overall design and usability of the maps, while a more focused consideration of symbols is addressed in later phases. Findings from this analysis were used to define content and design requirements that informed the user needs assessment in Phase 2 and the conceptual design of the analogue and augmented maps in Phase 3.

3.5 Phase 2 – User needs assessment

The second phase involved a user needs assessment conducted via an online questionnaire. The aim was to determine which objects and types of information users considered important on national park tourist maps, and how they perceived current maps and their content. The questionnaire combined closed and open questions to obtain both quantitative data and more detailed qualitative comments. Findings from this phase were used to outline user requirements and to inform the selection of content and functionality for the new analogue and AM designs. This is also explained in the paper by Cibilić and Poslončec-Petrić (2025).

Building on the competitive analysis of existing maps from Phase 1, this phase focused particularly on point symbols. Most thematic content on Croatian national park tourist maps is represented by point symbols (Medynska-Gulij, 2008); therefore, their design and use are crucial for effective perception and map reading (Konstantinou et al., 2023). The most effective cartographic symbols are those whose meaning is clear to the user (Halik and Medyńska-Gulij, 2017). Pictograms are intended to be interpreted correctly without prior learning or use of a legend and were found to be the most effective non-linguistic information that everyone understands (Sasaki and Yamamoto, 2019). Due to this advantage, they are usually included in maps for beginners and occasional users, such as tourists (Kostelnick et al., 2008). For this reason, they were the main focus of the user test within this research phase. All pictograms used in the questionnaire were derived from Croatian national park maps provided by the official institutions in Phase 1.

Croatian national parks can be grouped according to their dominant landscape and setting (see Figure 3.2). Brijuni, Kornati and Mljet are island parks; Sjeverni Velebit, Risnjak and Paklenica are mainly mountain parks; and Plitvice Lakes and Krka are the most visited national parks in Croatia, both located on rivers with lakes, waterfalls, and exceptional nature. The selection of pictograms included in the questionnaire was also distributed according to these groups: symbols were chosen from maps belonging to each group so that the questionnaire captured a variety of pictograms associated with different park types. This grouping was used only to ensure symbol diversity across park contexts, not to compare parks statistically. The specific distribution of pictograms across questions is described in the questionnaire subsection below.

3.5.1 Data Collection

An online questionnaire was used as the primary data collection instrument. This method was chosen for its effectiveness in reaching a diverse group of participants while preserving their anonymity, which was expected to encourage more authentic responses. Questionnaires are commonly used to collect quantitative data (Bergmann Martins et al., 2023), but they can also include questions designed to gather qualitative insights, depending on the evaluation's context. Recent studies on pictograms in tourist settings have also successfully employed online questionnaires, supporting the relevance of this method (Kovačević et al., 2024; Sasaki and Yamamoto, 2019).

The survey was conducted in August 2024 using Microsoft Forms. A link to the questionnaire was distributed via e-mail to national park institutions, nature park institutions, and major tourist agencies. To reach visitors more directly, printed flyers with a QR-code linking to the survey were also sent by post to national park institutions, with the intention of displaying them in visitor areas (see Appendix B). At the beginning of the questionnaire, participants were informed about the purpose of the study and presented with a privacy statement explaining how their data would be processed. Participation was voluntary and anonymous.

3.5.2 Participants

A total of 132 participants completed the questionnaire. Most were adults from Croatia (n = 81) and other parts of Europe (n = 43). The sampling strategy aimed to include a broad range of individuals, rather than a narrowly defined target group with specific needs (Taczanowska et al., 2019). This approach was intended to support the development of maps that are more universally accessible and appealing.

The age of participants ranged from 18 to 64 years, with the largest group between 25 and 34 years old (45%). One participant identified as non-binary, with 64 male and 67 female participants. In line with recommendations by Dowse and Ehlers (2010), questions about education levels were included to assess the distribution of educational backgrounds among respondents. The educational background of participants was as follows: 15.91% completed secondary (high school) education, 24.24% held a college or university diploma, 7.58% had completed undergraduate studies, and 52.27% obtained a master's degree or higher.

Participants were also asked to subjectively rate their experience with geographic information systems (GIS), maps, and other spatial tools. Based on these self-reports, respondents were roughly evenly divided between those with higher levels of experience and those with little or no experience. Following Ghayas et al. (2013), who noted that recognition of visual representations depends on memory and prior knowledge, this distinction between more experienced and less experienced participants was used later in the analysis to examine potential differences in pictogram comprehension.

3.5.3 Questionnaire

The questionnaire comprised three main sections. The first section collected demographic information, including age, gender, home country, educational background, and participants' self-assessed experience with GIS, maps, or other spatial tools.

The next section focused on pictogram comprehension. Pictogram understanding was assessed using both open-ended and closed-ended questions (ISO 9186-1:2014; Wolff and Wogalter, 1998). The questions were clearly formulated and maintained an appropriate level of complexity. Most were open-ended to reduce response rigidity and allow participants to express their interpretations in their own words. Closed-ended questions provided predefined response options, while open-ended questions invited free responses. Pictogram comprehension was evaluated according to ISO (9186-1:2014), with a 67% correct-interpretation rate set as the minimum criterion for acceptable comprehension. An answer was classified as correct if the participant's interpretation matched the intended meaning of the pictogram (Kovačević et al., 2024) as represented on the original map from which it was taken; otherwise, it was classified as incorrect.

Open-ended responses were coded into broader categories to support systematic comparison between the intended meaning and participants' interpretations (e.g., "hotel", "motel", and "hostel" were grouped under "accommodation"). Category definitions were derived from the content and legends of the evaluated national park maps, typical content on contemporary tourist maps, and relevant literature (Frangeš et al., 2019; Leung and Li, 2002). Coding was conducted in two passes: (1) initial assignment of each response to the most specific category; (2) refinement to merge synonymous labels (e.g., "hostel/hotel/motel"), split overly broad groupings when necessary, and confirm boundary cases. Responses were coded as "vague/unclear" when participants described the visual appearance of a symbol (rather than its intended function) or provided generic terms that could not be linked to a specific POI category. Ambiguous cases were flagged during coding and discussed with the supervisor to stabilise category boundaries.

In total, nine questions directly addressed pictogram comprehension. Two of these asked participants to choose their preferred symbol for a given meaning (e.g., "Which symbol best represents this object?"). Two further open-ended questions asked participants to indicate which symbols or objects they considered "most important" and "least important" on a tourist map. These questions aimed to inform future content selection and help identify which commonly used symbols are perceived as more or less important by the wider population. In the remaining five questions, participants were asked either "What do you think this pictogram means?" or to assign a given symbol to its meaning. These questions included pictograms drawn from different park groups, as follows:

- Question 1: pictograms from the Krka National Park map (waterfalls park group);

- Question 2: a pictogram from the Brijuni National Park map (island parks group);
- Question 3: pictograms from the Kornati (island parks group), Krka (waterfalls park group), Risnjak (mountain parks), and Mljet (island parks group) maps;
- Question 4: a pictogram from the Sjeverni Velebit National Park map (mountain parks);
- Question 5: pictograms from the Plitvice Lakes (waterfalls park group), Sjeverni Velebit (mountain parks), and Mljet (island parks group) maps;
- Question 6: a pictogram from the Sjeverni Velebit map (mountain parks) that also appeared, in slightly modified form, on all other maps;
- Question 7: pictograms from the Risnjak and Sjeverni Velebit maps (mountain parks), mainly because the maps in this group are at a smaller scale than the others and show more accommodation objects than maps at a larger scale.

Pictogram comprehension outcomes were explored across participants' self-reported map/GIS experience, as well as age and gender groups, using descriptive summaries of response distributions. As the distributions did not vary meaningfully by age or gender, these variables were not emphasised in the results; instead, the analysis focused on overall interpretation patterns and differences between more experienced and less experienced map users. This approach ensured that the questionnaire included a variety of pictograms from different park types. At the end of the questionnaire, participants were invited to provide a subjective evaluation of the survey itself and to leave additional comments about the research. The full questionnaire is provided in Appendix B.

3.6 Phase 3 – Conceptual design and AR prototyping

The third research phase focused on developing a design solution for the proposed AM concept by transforming the outcomes of the map analysis (Phase 1) and user needs assessment (Phase 2) into two comparable cartographic stimuli: an analogue map and an augmented map prototype. The earlier phases identified aspects of the current maps' content and symbolisation that influenced the design requirements. Detailed results from earlier phases supporting these inputs are presented in Chapter 4; here, the emphasis is on describing how these requirements were implemented through conceptual redesign and prototyping. As AMs are relatively novel within the cartographic domain, their usability was best assessed in comparison with a familiar benchmark that users already know how to use. Therefore, a traditional analogue map was used as the baseline condition, consistent with previous comparative research (Herman et al., 2018).

To enable a controlled comparison, the pictogram set, POI categories, scale, layout logic, and overall content density were kept consistent across conditions; the primary difference was the medium (paper-only versus paper plus virtual overlay) and the distribution of POI pictograms across layers.

3.6.1 Conceptual design approach

A central design assumption in this thesis was that AMs can contribute to cartographic generalisation by dividing tourist information into two layers: (1) a printed base map layer and (2) a virtual augmentation layer. This concept aimed to reduce the graphic load on the analogue map and to enable objects to be located closer to their true locations by avoiding the need for displacement or schematic placement of POIs in dense areas. The decision regarding which objects belong to the printed or virtual set was guided by user inputs from Phase 2.

As current national park maps contain different pictogram designs, the new stimuli were created using a standardised pictogram set, corresponding to national-level guidelines (Ministry of Economy and Sustainable Development, 2020b). In this way, the subsequent evaluation could concentrate on the effect of the visualisation medium (i.e., printed map versus AM) rather than on differences caused by inconsistent pictogram styles. The standard pictogram set was used in this thesis with permission.

The two map stimuli were designed as thematically comparable areas, allowing the analogue and augmented conditions to be compared within the same participants while minimising learning effects from repeated task types. Detailed justification of the within-subject design, counterbalancing procedure, and learning-effect mitigation is provided in Phase 5.

The two map areas were created as fictional environments to support controlled usability testing and reduce the risk of learning and carryover effects between conditions. They were designed to be thematically similar to Croatian national parks, including hydrographic features such as lakes, rivers, and waterfalls, as well as matching map scale and overall visual complexity. The same POI categories and pictogram set were used for both stimuli to ensure that any differences in performance could be interpreted primarily as reflecting the presentation mode rather than the content. To keep the stimuli readable and to avoid unnecessary cognitive load during usability testing, the amount of task-relevant POI content was deliberately limited to a manageable set (Moacdieh and Sarter, 2015; Rosenholtz et al., 2007; Touya et al., 2016). Symbolisation was also kept consistent across both stimuli to support perceptual grouping and facilitate efficient interpretation (Wagemans et al., 2012; Żyszkowska, 2016). The distribution of POI pictograms between the analogue and augmented maps is shown in Table 3.2.

Table 3.2 Distribution of POI pictograms between the analogue and augmented maps

POI objects	Total POIs	Printed on analogue map	Printed on the AM paper layer	Shown in the AR overlay
Information point	5	3	2	0
Waterfalls	5	2	3	0
Parking lot	5	3	2	0
Boat harbour	4	2	2	0
Toilet (v1) / Viewpoint (v2) *	4	2	0	2
Restaurant	3	1	2	0
Coffee shop	3	2	1	0
Souvenir shop	3	1	0	2
TOTAL	32	16	16	

**In the refined version used in Phase 5, the toilet pictogram in the initial prototype was replaced with a viewpoint; this change did not alter the total POI counts or the 16/16 split between printed and virtual content.*

3.6.2 AM prototyping decisions

The AM prototype followed published AR design heuristics (Dünser et al., 2007; Endsley et al., 2017; Krauß et al., 2021; Vi et al., 2019) and design recommendations from companies actively developing XR hardware and software, such as Apple (2024), Google (2024), and Microsoft (2021). While AR can also augment other senses, multimodal AR introduces additional design and usability challenges (Endsley et al., 2017). Therefore, this thesis focused on vision-based augmentation to maintain a controlled comparison centred on map use. The prototype was designed for a handheld mobile device to better reflect realistic tourist behaviour (Livingston et al., 2005). For this reason, mobile map design recommendations were also considered, including limited display space and users divided attention while moving (Kuparinen, 2016; Schulz et al., 2021). The augmented stimulus was implemented as a marker-based prototype. Marker-based AR applications use a visual target (in this case, a printed map) to trigger and spatially align virtual content (Kato and Billinghurst, 1999; Mendoza-Ramírez et al., 2023). After detecting the marker through the device camera, the system estimates its position and orientation and overlays digital elements on top of it (Carmigniani et al., 2011). This approach was selected because it enabled stable alignment of virtual content to a map surface and supported rapid prototyping, which was appropriate at this stage of a formative UCD cycle (Endsley et al., 2017; Nielsen, 1993). It should be noted that the tracking method itself was not evaluated within this research; the focus was on the cartographic layering concept. Because AR performance and perception depend on viewing distance, angle, and lighting, the AM prototype was designed as a large-format map to support consistent legibility and stable marker detection during standing, real-world-like use (Endsley et al., 2017). It also reflected the practical tourism context in which large, printed overview maps are commonly used as shared information spaces. In this regard, Grubert et al. (2014) evaluated handheld Magic Lens use on large touristic map posters and showed that workspace size and the physical setup affect performance and usability, supporting the wall-map testing context. Therefore, the maps were printed in A2 format and displayed as wall maps during testing in the following phases.

The AR content consisted of static, non-interactive 2D pictogram overlays, intentionally kept simple to minimise additional cognitive and interaction confounds of 3D or animated objects (Dong and Liao, 2016; Herman et al., 2018). This choice ensured that the two map conditions remained comparable, as the key difference was the medium and information layering rather than additional interface functionality. During implementation, the number of virtually displayed objects was kept limited to avoid performance constraints and tracking instability (Labrie and Cheng, 2020).

To ensure transparency and replicability, the design requirements and corresponding implementation decisions are summarised in Appendix C.

3.6.3 Analogue map production in QGIS

After the initial paper sketches and mock-up creation, the base cartographic stimuli were designed and created in QGIS (version 3.34.15), in accordance with cartographic design principles and guidelines (Dent et al., 2009; Kraak and Ormeling, 2010; Lovrić, 1988; Slocum, 2014; Tyner, 2010). As discussed, the fictional maps were designed to resemble the thematic character of Croatian national parks and to meet cartographic requirements for clarity and balanced structure. Thematic layers and map elements (e.g. hydrography, paths, area structure) were assembled to form a balanced tourist map context. Pictograms representing POIs were added as point features. The analogue map stimulus included all selected POIs, reflecting traditional map constraints observed in Phase 1, where dense POI clusters required careful cartographic generalisation to maintain readability. In the AM condition, the printed base map layer contained only the POIs allocated to the printed layer, while the remaining POIs were available in the virtual augmentation layer (Table 3.2).

For use in later evaluation phases, the final analogue map was exported from QGIS as a print-ready PDF. In addition, a 300 DPI PNG version of the adjusted map layout was exported and used as the marker image for tracking in the AR prototype. Minor graphic adjustments were made in Inkscape (version 1.4, 86a8ad7, 2024-10-11) to prepare the print outputs.

3.6.4 AR map prototyping in Unity

The AM prototype was developed in Unity 6 (version 6000.0.35f1) using AR Foundation (version 6.0) for marker-based tracking on a handheld mobile device. This platform provides a widely used, cross-platform environment for rapid AR prototyping and reliable image-target tracking. The workflow followed a straightforward pipeline: (1) project setup and AR tracking configuration, (2) registration of the printed map as the marker target, (3) import of pictogram sprites, (4) positioning the virtual POIs relative to the map plane, and (5) deployment of the prototype to the target device. Virtual POI positions were manually placed in the local coordinate system of the tracked map plane, following the printed map reference.

Before expert evaluation, the two stimuli were internally checked to confirm: (1) legibility of printed symbols and map elements, (2) consistency of pictograms and POI categories across conditions, (3) stable marker detection under typical indoor lighting, and (4) visually acceptable alignment of virtual symbols to the printed map surface. The resulting maps were then used in the expert-based phase. Following expert evaluation (Phase 4), the stimuli were iteratively refined, and the revised versions were used in Phase 5; details of the improvements are documented in the Phase 4 outcomes.

3.7 Phase 4 – Expert cartographic review and formative refinement

In the fourth phase, experienced cartographers, as domain experts, evaluated the analogue and augmented map prototypes produced in Phase 3. Using a task-based walkthrough supported by a think-aloud protocol and semi-structured discussion, they commented on the cartographic correctness, visual consistency, and legibility of both prototypes, as well as the integration and perceived added value of AR content, and any potential issues related to perception and cartographic balance. The aim was to identify potential cartographic, perceptual, and interaction issues early, and to use expert recommendations to refine both map stimuli and the user-testing protocol before the final user study (Phase 5), serving as a formative expert check within the iterative UCD process described in this chapter.

3.7.1 Participants

Seven cartography experts participated in this phase (three men and four women), recruited from both academia and industry. Each had at least ten years of professional experience in map design and production. This sample size is consistent with UCD practice in both HCI and cartography, where formative reviews typically rely on a small group of experienced evaluators to efficiently identify design issues before larger-scale user testing (Alroobaea and Mayhew, 2014; Bergmann Martins et al., 2023). Participants were invited through informal contacts; all invited experts agreed to participate and were included in the evaluation.

3.7.2 Study setup and materials

Sessions were conducted individually in a semi-controlled laboratory setting at the Faculty of Geodesy, University of Zagreb (Kačićeva 26, room 133) in March and April 2025. Each session lasted up to one hour and was conducted in Croatian. At the start of each session, participants received a short briefing and signed an informed consent form. A camera with integrated microphone was used to capture participants' verbal feedback and observable behaviour, supported by researcher notes. Recordings were stored securely and analysed using anonymised participant codes.

The stimuli consisted of two similar A2 analogue maps. The virtual content was presented on a Samsung Galaxy Tab S7 Android tablet running the AR application, using one of the printed maps as the tracking marker. The tablet was used because of its larger screen size compared to a mobile phone. To facilitate comparative evaluation, the maps were presented side by side (rather than one at a time), enabling experts to evaluate each map in relation to the other, and to comment on differences and consistencies across conditions. Figure 3.3 shows the laboratory setup, which was later reused in Phase 5 to maintain the same viewing conditions across evaluation phases.

Figure 3.3 Laboratory setup for expert's review of map stimuli

A structured evaluation sheet was used to guide feedback and ensure all key criteria were addressed. It included open-ended prompts to elicit detailed qualitative feedback from three complementary perspectives:

- Usability (ease of understanding, finding POIs, consistency, satisfaction; and, for AR, clarity and smoothness of interaction with virtual elements);
- Cartographic principles (pictogram recognisability, symbol size, layer differentiation, label placement, scale suitability, spatial plausibility, orientation);
- Cognitive load and information processing (overload versus lack of information, confusing elements, search ease, memory burden, switching between analogue and virtual content, perceived interaction constraints).

Additionally, the session incorporated a cognitive walkthrough to review the task set prepared for Phase 5, focusing on task realism, difficulty balance, and the ability of tasks to reveal differences between the analogue and augmented conditions. The task set included symbol interpretation, POI search, distance comparison, identifying the nearest target from a starting location, and shortest-path description, with an additional comparative proximity question applicable to both maps. A detailed description and justification of the task design is provided in Phase 5, where the tasks are implemented in the user study.

3.7.3 Procedure

Each session followed a semi-structured protocol. After a brief introduction and consent, participants were informed about the purpose of the session. They were asked to think aloud while inspecting the maps, verbalising what they noticed and why particular elements supported or hindered map reading. They evaluated the two stimuli by first familiarising themselves with each map and answering the planned protocol questions while verbalising their observations. Although both maps were physically visible side by side to support comparison, the discussion was structured map by map: participants first commented on the analogue map using the evaluation sheet prompts, then on the augmented map, after which they compared them intuitively. After both map conditions were reviewed, participants commented on the planned Phase 5 task set - particularly task wording, realism, and difficulty balance. Some participants completed selected tasks directly on the stimuli, while others reviewed the tasks conceptually and discussed how users would approach them. In both cases, feedback was elicited using the same think-aloud and semi-structured protocol. Each session concluded with an open discussion on overall impressions and recommendations for improving the maps and the planned user test.

3.7.4 Data collection and analysis

All sessions were audio- and video-recorded to capture both verbal feedback and interaction behaviour. Recordings were reviewed and expert comments were analysed qualitatively: responses to the open-ended prompts were first organised deductively according to the predefined evaluation dimensions (usability, cartographic principles and cognitive load) and then further coded inductively into more specific themes (e.g., symbol legibility, label placement, hierarchy, AR overlay behaviour). Coding was performed in two passes (initial coding and subsequent refinement). Any ambiguous cases and theme boundaries were discussed with the supervisor to improve consistency. Findings from this phase directly informed iterative refinements of the stimuli design. Issues were prioritised when raised by multiple experts. Key changes resulting from this phase are reported in the Results chapter.

The full test plan, technical specifications, informed consent form, and additional setup images are provided in Appendix D in Croatian, as administered during data collection.

3.8 Phase 5 – User-based usability evaluation

The final phase consisted of a controlled, task-based usability evaluation comparing an analogue tourist map with an augmented map presented through a mobile AR interface. The aim was to determine whether the augmented condition affected user performance and perceived usability for typical tourist-map tasks, while also gathering qualitative feedback on comprehension, interaction, and design clarity. The study combined objective evaluation metrics (task success and completion time), indicating how effectively and efficiently users could find, interpret, and use map information, with subjective usability ratings (assessed through a System Usability Scale questionnaire, SUS) and qualitative feedback collected through post-test questions. This phase provided the main quantitative and qualitative data needed to evaluate the map's perceived value and usefulness.

3.8.1 Study design

As discussed in Phases 3 and 4, the usability of the analogue and augmented maps was evaluated by comparing user performance across two map conditions. This comparison can be conducted using either a between-subjects or within-subjects design (Lazar et al., 2017). A within-subjects approach was adopted, meaning each participant completed the tasks with both maps. This approach typically provides higher statistical power with a moderate sample size and reduces the influence of individual differences (e.g., spatial ability) on the comparison (Lazar et al., 2017). It also supports the aim of determining whether the same user performs differently depending on the map medium.

A common limitation of within-subjects designs is the risk of learning and carryover effects (Lazar et al., 2017). To minimise this, the stimuli were designed to be similar but not identical, using map areas that are comparable in theme and complexity. Using the same geographic area in both conditions would increase the risk of learning effects, as participants may remember locations from the first map. At the same time, it is difficult to find two real locations that are sufficiently similar while also ensuring that participants have not visited them before. Therefore, two fictional map areas were created (Phase 3). This approach enabled controlled manipulation of map content based on user inputs from Phase 2 while keeping the two stimuli thematically similar and comparable for usability testing. To further control order effects in the within-subjects design, the presentation sequence of map conditions (analogue map first vs. augmented map first) was counterbalanced, with an equal number of participants assigned to each map viewing order, so that potential learning or fatigue effects were balanced across conditions.

3.8.2 Participants

The usability study involved 48 participants, 26 women and 22 men. Participants ranged in age from 20 to 70 years, providing a broad adult sample consistent with the target audience of tourist maps. This sample size aligns with recommendations and reported practice in cartographic user studies (Bergmann Martins et al., 2023). No compensation was provided for participation.

Recruitment followed a semi-controlled approach, combining wide outreach with targeted invitations to achieve a heterogeneous user group rather than a narrowly defined sample. Participants were recruited via social media platforms, a printed flyer displayed in a shared faculty building, and personal connections. This strategy was used purposefully to include diversity in key user characteristics related to tourist map use, such as gender and age, as well as differences in spatial orientation, travel habits, and wayfinding experience, so that the evaluation captures a greater variety in the intended user population. This approach aligns with usability practice that emphasises recruiting participants who represent the expected range of user characteristics and context-of-use factors, instead of treating "the user" as a single, homogeneous profile (Maguire, 2001). Practical multi-channel recruitment strategies (including social networks and personal contact) are also outlined in usability testing guidance and HCI research methods (Lazar et al., 2017; Rubin et al., 2008).

To support the within-subject comparison, participants were divided equally between the two presentation orders (24 completed the analogue condition first, followed by AM; 24 completed the AM condition first, followed by analogue). In the pre-test questions, participants generally indicated they were comfortable using maps (M = 4.02, median = 4 on a five-point scale) and that they travelled quite frequently (M = 3.52, median = 4), which is helpful in a tourist map usability study because it suggests they can quickly understand the task framing and bring realistic expectations about how a map should work. Participants also reported frequent smartphone-based navigation (M = 3.44, median = 4), suggesting digital wayfinding is part of their everyday practice. At the same time, self-reported familiarity with AR was relatively low (M = 2.46, median = 2.5), which was considered a potential factor when analysing initial performance and perceived usability ratings (SUS scores). All participants had normal or corrected-to-normal vision; visual impairment and AR-related discomfort were explicitly checked in the introductory questions. All participants completed the full protocol; no sessions were excluded due to technical issues.

In addition to basic information, spatial ability was measured using the Santa Barbara Sense of Direction (SBSOD) questionnaire. The SBSOD is a brief, standardised questionnaire designed to assess individuals' confidence in everyday orientation and wayfinding (Hegarty et al., 2002). It was included to aid interpretation of performance differences between the analogue and AM conditions, considering variations in spatial orientation skills. Educational level was not assessed, as participant profiling focused on factors more directly related to task-based map use, namely spatial ability and navigation experience.

3.8.3 Study setup and materials

Individual sessions took place in a controlled laboratory environment at the Faculty of Geodesy, University of Zagreb (Kačićeva 26, room 133) in May and June 2025. Each session lasted up to 20 minutes and was conducted in Croatian. At the start of each session, participants received a brief overview and signed an informed consent form. A camera with an integrated microphone recorded participants' verbal feedback and behaviour. Recordings were stored securely and analysed using anonymised participant codes. Environmental conditions, such as lighting and background noise, were kept constant across sessions to minimise external influences on task performance.

The study used two thematically similar A2 printed map stimuli. In the augmented condition, virtual content was displayed on an Android tablet running the AR application, with one of the printed maps serving as the tracking marker. A tablet was chosen due to its larger screen size compared to a mobile phone. To ensure each map was evaluated independently, the maps were displayed one at a time rather than side by side and mounted on a rotating board so that only the map currently being evaluated was visible (Figure 3.4).

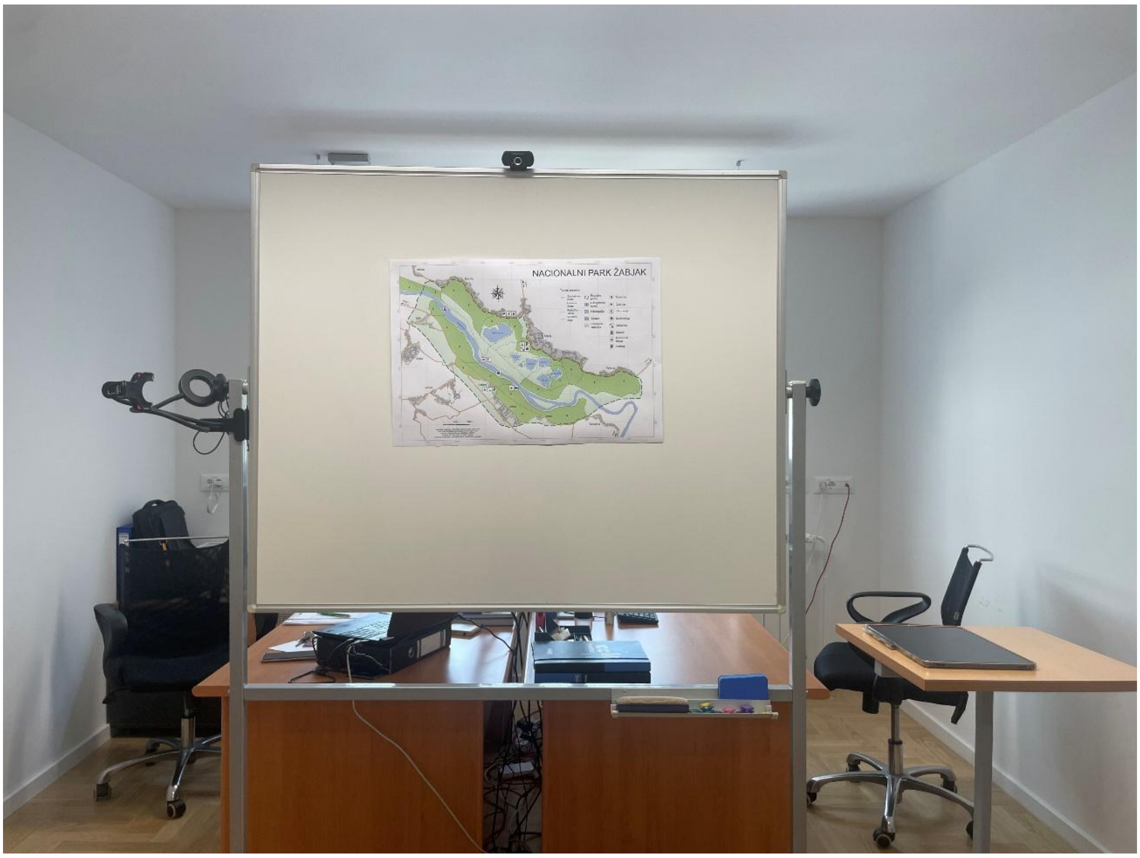


Figure 3.4 Laboratory setup for usability user test of map stimuli

3.8.4 Tasks and measures

Because map use is inherently goal-oriented, usability can only be meaningfully assessed when users attempt to complete realistic map-reading goals. In experimental cartographic evaluation, the task set should be closely tied to the intended purpose of map use (Board, 1978). Following this logic, the usability tasks were designed to reflect the typical actions a visitor performs when using a tourist map, while remaining structured enough for controlled comparison between the analogue and augmented maps. Each participant completed six tasks per map, progressing from easier interpretation and search activities to more demanding navigation and planning tasks. The sequence begins with basic symbol decoding (“What does this symbol represent?”), as recognising and interpreting symbols is a fundamental prerequisite for successful map-reading. It then moves to more goal-directed tasks: locating relevant POIs (search), judging which facility is closer (comparison of relative distance), identifying the nearest option from a stated starting point (spatial understanding), and finally selecting and describing the shortest route (planning and path-following). For tasks involving proximity (closer/nearest), distance was defined as distance along the path (not straight-line distance), and this was stated in the task delivery. The task set was intentionally designed to consider symbol positions: clustering and displacement of symbols on the analogue map can obscure proximity relationships, while on the augmented map, reduced POI density on the printed layer enables symbols to be placed closer to their mapped locations. For this reason, tasks questioning “which is closer” (comparison of relative distance, i.e., Tasks 3 and 6) directly test the hypothesis about supporting more accurate perception of POI location.

This progression aligns with task-taxonomy and interaction-primitive frameworks used in cartography and geovisualisation research (Herman et al., 2018; Juřík et al., 2018; Roth, 2013). In particular, Roth (2013) positions search as a core action supporting fundamental objectives such as identifying and comparing, while Juřík et al. (2018) similarly treat search and spatial-understanding as building blocks, and argue that more complex tasks, such as planning, are more likely to reveal differences between conditions - an approach also reflected in Herman et al. (2018). A similar logic appears in broader visual-analysis task classifications, which distinguish between search, spatial understanding, and estimation, and explicitly recognise path-following as a relevant supporting task (Laha et al., 2015). Finally, the tasks were framed as realistic visitor questions to preserve contextual validity and maintain an appropriate context of use (Maguire, 2001). To keep the comparison fair, tasks were paired across conditions so that type and difficulty were comparable, while the specific target locations varied to reduce simple memorisation effects. To provide a clear overview of this paired design, the full task set is summarised in Table 3.3.

Table 3.3 Usability tasks for the analogue and augmented map conditions

Task no.	Task type	Difficulty	Analogue map task wording	Augmented map task wording
1	Symbol understanding (interpretation)	Easy	What does this symbol represent? (Souvenir shop)	What does this symbol represent? (Toilet)
2	POI finding (search)	Easy	Find the toilet closest to the café in the northern part of the park.	Find the souvenir shop closest to the restaurant in the eastern part of the park.
3	Distance comparison (search/comparison)	Medium	Is the café in the northern part of the park closer to the toilet or the souvenir shop?	Is the restaurant in the eastern part of the park closer to the toilet or the souvenir shop?
4	Nearest facility from a start point (navigation)	Medium	You are at the southern car parking. Where is the nearest souvenir shop?	You are at the western information centre. Where is the nearest toilet?
5	Shortest route (navigation/planning)	Hard	Find the shortest route from the restaurant to the toilet and describe it.	Find the shortest route from the café to the souvenir shop and describe it.
6	Distance comparison (search/comparison)	Medium	What is closer to the restaurant — the toilet or the souvenir shop?	What is closer to the café — the toilet or the souvenir shop?

Note: For Task 4, “nearest” refers to distance along the path network, not straight-line distance.

Task administration used a structured evaluation sheet to ensure consistent instruction delivery and comparable coverage among participants. Performance was recorded for each task in both map conditions. Effectiveness was measured as task success (correct/incorrect), and efficiency as task completion time (in seconds), derived from video recordings using the task start and end timestamps. Task start was defined as the moment the evaluator finished reading the task, and task end as the moment the participant provided a final answer. Correctness was scored based on whether the participant gave the correct answer for the given task. Routes were scored as correct if the described path followed the shortest path on the map; any tied-shortest option was accepted, and clear detours were evaluated as incorrect. To check scoring consistency, scoring was completed in two separate passes, with any discrepancies resolved before analysis. After each condition, participants rated perceived usability using the SUS, a brief, standardised questionnaire that provides a reliable and comparable overall usability score for interactive systems (Brooke, 1996). The SUS was administered after every map condition to capture participants perceived usability of the analogue and augmented map interfaces. Qualitative feedback was collected through post-test questions, supported by video recordings and researcher notes.

3.8.5 Procedure

Each session followed a structured protocol based on the Phase 5 usability testing script (available in Appendix E, in Croatian). After a brief introduction, participants signed an informed consent form. They then answered a short set of pre-test questions about their map use, travel experiences, familiarity with AR, smartphone navigation use, and any visual or comfort problems that could affect their map reading abilities. This was followed by the SBSOD questionnaire to capture individual differences in self-reported orientation and wayfinding skills. The main part of the session consisted of task-based testing in both map conditions. Before the tasks began, participants were given a short time to familiarise themselves with the map. Participants answered the full task set with the first map condition, after which they completed the SUS questionnaire specific to that map. The same process was then repeated with the second map condition, followed by the SUS questionnaire for the second map. As already mentioned, the order of conditions (analogue first vs augmented first) was counterbalanced among participants, but the session structure remained the same regardless of order. Each session ended with a short discussion during which participants shared their overall experience, compared the two map conditions in terms of intuitiveness and difficulty, and offered recommendations for improvement. Each session lasted approximately 20 minutes.

3.8.6 Data analysis

Based on the tasks set out in Table 3.3 and the selected outcome measures, Phase 5 was guided by the following operational hypotheses:

- (H5.1) For search and comparison tasks (Tasks 2, 3, and 6), participants would achieve higher task success and/or shorter completion times in the augmented condition.
- (H5.2) For navigation and planning tasks (Tasks 4 and 5), participants would show improved success and/or shorter completion times in the augmented condition.
- (H5.3) Participants would rate the augmented map as at least as usable, and likely more usable, than the analogue map, as measured by SUS scores, while design and visual impressions would serve as qualitative contextual evidence.
- (H5.4) Higher SBSOD scores were expected to be associated with better task performance (higher success and/or shorter completion times) in both conditions.

Task 1 served as a baseline check of pictogram comprehension and was completed in the same manner in both conditions (printed pictogram recognition without AR support); therefore, it was not included among the operational hypotheses.

Task success (correct/incorrect), task completion time (s), and SUS scores were analysed separately for the analogue and augmented conditions using within-subject comparisons. For each participant, overall effectiveness was summarised as the proportion of correctly completed tasks per condition, and efficiency as the mean task completion time per condition; efficiency was examined both across all attempts and for correct trials only. Normality checks guided the choice between paired parametric and non-parametric tests for continuous outcomes (e.g., completion time and SUS). Task effectiveness (paired correct/incorrect outcomes) was compared using matched-pairs tests appropriate for binary data. Specifically, paired t-tests or Wilcoxon signed-rank tests were used for continuous outcomes (time and SUS), and McNemar's test was used for paired binary task success where appropriate. As map order was counterbalanced, potential order effects were checked by comparing key outcome measures between the two order groups. Qualitative responses from the post-test questions were analysed thematically to identify recurring usability issues and to contextualise the quantitative results.

3.9 Chapter summary

This chapter explains how the UCD methodology was adapted into a five-phase research process for designing and evaluating augmented tourist maps for Croatian national parks.

Throughout these phases, cartographic communication principles and usability engineering practices were applied in an integrated way: early map analysis and user input guided design and prototyping decisions, expert feedback supported formative refinement, and the final phase provided a controlled basis for comparing the analogue and augmented map conditions. The next chapter presents the results for each phase (Phases 1–5), following the same structure and concluding with the Phase 5 usability outcomes.

4 RESULTS

This chapter presents the results of the five-phase UCD methodology described in Chapter 3. The results are reported in the order in which the phases were conducted, as each phase either informed the next design step or led to formative refinements before the final usability evaluation. Consequently, Phases 1–4 mainly produced qualitative, design-focused evidence (such as gaps in existing maps, user needs, and expert feedback), while Phase 5 provided the main comparative usability findings for the analogue and augmented map conditions.

4.1 Phase 1 Results – Competitive analysis of existing maps

Phase 1 examined the current state of analogue tourist maps used in Croatian national parks, aiming to identify strengths, weaknesses, and recurring design patterns that could inform both the needs assessment (Phase 2) and the subsequent redesign and prototyping work (Phase 3). Eight maps were analysed in total: one representative map per park, selected from the materials provided by each national park institution. The analysis was qualitative and descriptive, focusing on how basic cartographic elements and design decisions support or hinder typical tourist map use.

4.1.1 Cross-park comparison

The analysis showed that these maps are highly variable in cartographic completeness and consistency: even when maps communicate similar types of tourist information, fundamental map elements and design conventions are applied unevenly from park to park. To make this variability explicit, the maps were compared using a structured checklist of basic cartographic elements. Because symbol sets differ substantially between parks, pictograms were not evaluated as an isolated category in this phase; instead, they were considered as part of the overall map design. Table 4.1 summarises the comparative results across the eight national parks (one map per park), highlighting which basic elements are present, missing, or inconsistently implemented.

Table 4.1 Comparison table between Croatian national park maps (reproduced from Cibilić and Poslončec-Petrić, 2025)

	Brijuni	**Kornati**	**Mljet**	**Paklenica**	**Risnjak**	**Sj. Velebit**	**Krka**	**Plitvice lakes**
Title	YES	YES	YES	NO	YES	NO	NO	YES
Multilingual title	NO	YES	YES	NO	YES	NO	NO	YES
Position of the title	GOOD	BAD	GOOD	NO	GOOD	NO	NO	GOOD
Map dimension (size)	60 × 47 cm	42 × 30 cm	63 × 93 cm	15 × 21 cm	46 × 30 cm	21 × 30 cm	15 × 21 cm	103 × 56 cm
Map orientation	NORTH	NORTH	NORTH	NORTH	NORTH	NORTH	NORTH	WEST
North arrow	YES	YES	YES	NO	YES	YES	NO	YES
Scale (value)	1:30,000	1:100,000	1:15,000	1:40,000	1:80,000	1:20,000	1: 20,000	1:30,000
Scale (format)	YES Graphic	NO	YES Graphic	NO	YES Graphic	YES Numeric	NO	YES Graphic
Map format	60 × 47 cm	42 × 30 cm	68 × 98 cm	15 × 21 cm	48 × 33 cm	21 × 30 cm	15 × 21 cm	106 × 66 cm
Contour interval	NO	NO	5 m	5 m	NO	10 m	NO	NO
Altitudes and depths	NO	NO	YES [m]	YES [m]	YES [m]	YES [m]	NO	YES [m]
Nomenclature	NO	NO	YES	NO	NO	NO	NO	NO
Projection	NO	NO	YES	NO	NO	NO	NO	NO
Ellipsoid	NO	NO	YES	NO	NO	NO	NO	NO
Coordinate grid	NO	YES	YES	YES	NO	YES	NO	NO
Map content settlements	NO	NO	YES	YES	YES	YES	YES	YES
Map content roads	NO	NO	YES	YES	YES	YES	YES	YES
Map content water bodies	NO	NO	YES	YES	YES	YES	YES	YES
Map content relief	NO	YES	YES	YES	NO	YES	NO	YES
Map content vegetation	NO	YES	NO	NO	NO	NO	NO	NO
Map content geographic names (toponyms)	YES	YES	YES	YES	YES	YES	YES	YES
Legend	YES	NO	YES	NO	YES	NO	YES	YES
Legend completeness	NO	NO	YES	NO	YES	NO	NO	YES
Legend categorization	YES	NO	YES	NO	NO	NO	YES	YES
Legend multilingual	YES	NO	YES	NO	YES	NO	NO	YES
Map graphics difference between symbols on the map vs. legend	YES	YES	YES	YES	YES	NO	NO	NO

Map graphics text position and style	BAD	BAD	GOOD	BAD	GOOD	BAD	GOOD	GOOD
Map elements positioning	GOOD	BAD	GOOD	BAD	BAD	BAD	GOOD	GOOD
Graphics density	GOOD	BAD	GOOD	BAD	BAD	BAD	GOOD	GOOD
Generalizatio n	GOOD	BAD	GOOD	BAD	BAD	BAD	GOOD	GOOD
Author	YES	YES	YES	NO	YES	NO	NO	NO
Printing and copyrights	NO	NO	YES	NO	NO	NO	NO	NO
Publisher	NO	YES	YES	YES	NO	NO	NO	NO
Publication date	NO	YES	YES	NO	NO	NO	NO	NO
Sources	NO	NO	YES	NO	NO	NO	NO	NO
Additional data	YES	YES	YES	NO	YES	NO	NO	NO
Map frame	NO	NO	YES	NO	YES	NO	NO	YES
Inserted map	YES	NO	YES	NO	NO	NO	NO	YES
Expanded map	NO	NO	NO	NO	NO	NO	NO	NO
Index or list of objects	YES	NO	NO	NO	NO	NO	NO	NO

A simple cross-map review illustrates the extent of this inconsistency. Three of the eight maps lacked a legend entirely, and three did not provide a usable scale. Projection and ellipsoid information appeared only on the Mljet map, while map frames were present on just three maps. Titles were also missing from three maps. Apart from geographic names, which appear consistently, most interpretive support elements varied significantly from park to park.

Overall, Table 4.1 shows that the existing map set does not provide a consistent cartographic baseline across parks. Although the maps often aim to support similar tourist activities, core interpretive elements – most notably the legend, scale, projection or metadata, and symbol clarity – are applied inconsistently or are missing altogether, resulting in substantial variation in cartographic completeness across parks.

A structured comparison further shows that only some maps provide a complete set of fundamental elements, such as a clearly presented title, a legible legend, a usable scale, a stable frame, and a coherent graphic hierarchy. Others omit several core elements simultaneously, increasing the user's cognitive effort to interpret the map and raising the likelihood of uncertainty during basic map-reading tasks. This was especially evident in the handling of the legend: several maps either lacked a legend entirely or provided one that did not fully correspond to the map content, for example by omitting certain path categories, thematic routes, or transport lines shown in the map body.

Beyond missing structural elements, the analysis also identified inconsistent handling of graphic design and generalisation across the map set. Some maps appear visually balanced and readable, with clear separation between base information and thematic content, while others are affected by clutter, weak typographic contrast, or inconsistencies between symbols shown in the legend and those used on the map. Taken together, the comparison suggests that no unified cartographic standard is applied consistently across the national park map set, and these issues reduce the maps' reliability as communication products.

4.1.2 Park-specific findings

Although cross-map comparison highlighted shared problems, each analysed map also displayed specific design characteristics that demonstrate how the same general issues manifest differently in practice.

The Brijuni map uses a digital orthophoto background, which lacks explicit cartographic representation of several standard content layers, notably settlements, vegetation, and relief. While a multilingual legend is present, it does not cover all mapped features, such as the ferry line and certain paths. Additionally, the geographical names are difficult to read due to low-contrast white text that does not follow the terrain.

The Kornati map is notably deficient in basic interpretive support, particularly due to the absence of both a legend and a scale. The lack of clear graphical elements and a proper frame reduces the map's usefulness for independent navigation and planning.

The National Park Mljet map is the most complete and conventionally cartographic product in the set. It includes multiple base layers – settlements, roads, hydrography, and relief with contour lines – and is described as readable and relatively complete compared to the other parks.

The Paklenica map presents a particularly challenging example, as it lacks a title, scale, legend, and projection information. The map contains several symbols, such as park entrances, which are not explained, making navigation and interpretation especially difficult for users. Similarly, the Sjeverni Velebit map displays the same general pattern of insufficient supporting elements, limiting usability for tourists who rely on the map as a primary information source.

The Risnjak National Park map lacks key structural components, such as relief representation and grid lines. Although a legend is present, inconsistencies in symbol size between the map and the legend reduce interpretive clarity. The absence of a frame and explanatory text further weakens the map as a self-explanatory product.

On the Krka map, settlements are represented with point symbols of varying sizes (suggesting a hierarchy, likely by population), but the legend does not clearly explain this differentiation. Similarly, some thematic routes (such as educational trails and bicycle routes) are shown on the map but not represented in the legend, introducing uncertainty during interpretation.

The Plitvice Lakes map provides relatively good graphic density overall, but readability issues arise in the typographic treatment of labels (for example, inconsistent font sizes for lake names). In addition, relief shading is visually dominant in some areas, which can disrupt balance and compete with thematic information. Maps included in the analysis are available in Appendix A, together with a detailed written analysis for each map.

4.1.3 Design implications for subsequent phases

Taken together, the Phase 1 results showed that, although Croatian national park maps often contain similar types of tourist information, they vary widely in how consistently that information is organised, symbolised, and supported for interpretation. This variability highlights a clear need for refinement and improvement, and it also influenced the direction of the subsequent phases. The specific gaps and recurring design patterns identified here were used to frame a more focused user needs assessment in Phase 2, targeting the elements that visitors rely on most when completing typical tourist map tasks. The variability and inconsistency in symbol design, together with uneven handling of density and hierarchy across the analysed maps, highlighted generalisation and symbol clutter as issues that should be addressed more carefully in the subsequent phases. At the same time, Phase 1 provided the practical baseline for Phase 3 by informing the redesign and development of a controlled, standardised analogue map and its augmented counterpart, ensuring that the prototypes directly addressed the shortcomings observed in the existing map set.

4.2 Phase 2 Results – User needs assessment

Phase 2 involved a user needs assessment conducted through an online questionnaire, building on the inconsistencies identified in Phase 1. The aim was to understand how users interpret and perceive current map content, and which objects and types of information they consider important on national park tourist maps. Because pictograms carry most of the thematic information on these maps, their design and interpretability are crucial for effective map reading. In contrast to map analysis, Phase 2 addressed pictograms directly by testing users' understanding of commonly used symbols and by collecting user input on map content priorities. The questionnaire structure and question types are described in Chapter 3; in this chapter, the focus is on what the responses revealed and how these findings shaped later design decisions. The results from this phase were used to outline user requirements and priorities that guided the selection of content and the intended functionality for the maps developed in Phase 3.

4.2.1 Pictogram preference and comprehension

In addition to the main pictogram comprehension tasks, the questionnaire included two short closed-ended preference items to capture practical symbol preferences for Phase 3. These questions asked participants to select (1) their preferred toilet pictogram (two variants) and (2) the symbol that best represents a viewpoint (six variants); the pictograms are shown in the full questionnaire in Appendix B. For the toilet symbol, participants preferred Option 1 (61%) over Option 2 (39%). For the viewpoint symbol, responses were concentrated on two options, with Option 2 selected most often (46%), followed by Option 3 (37%), while the remaining options were chosen less frequently (Option 4: 11%; Option 1: 3%; Option 5: 2%; Option 6: 1%). These preference results were used as design input for symbol selection during map development in Phase 3, and were excluded from the comprehension evaluation.

Pictogram comprehension was evaluated according to the ISO (9186-1:2014) criterion, which sets an interpretation accuracy of 67% as the minimum threshold for acceptable understanding. Across the pictogram set derived from existing Croatian national park maps, only four pictograms were interpreted correctly by more than two-thirds of participants, whereas seven pictograms fell below the minimum criterion (Figure 4.1). This pattern suggests that many currently used pictograms on these maps may not function as reliable cues for typical users.

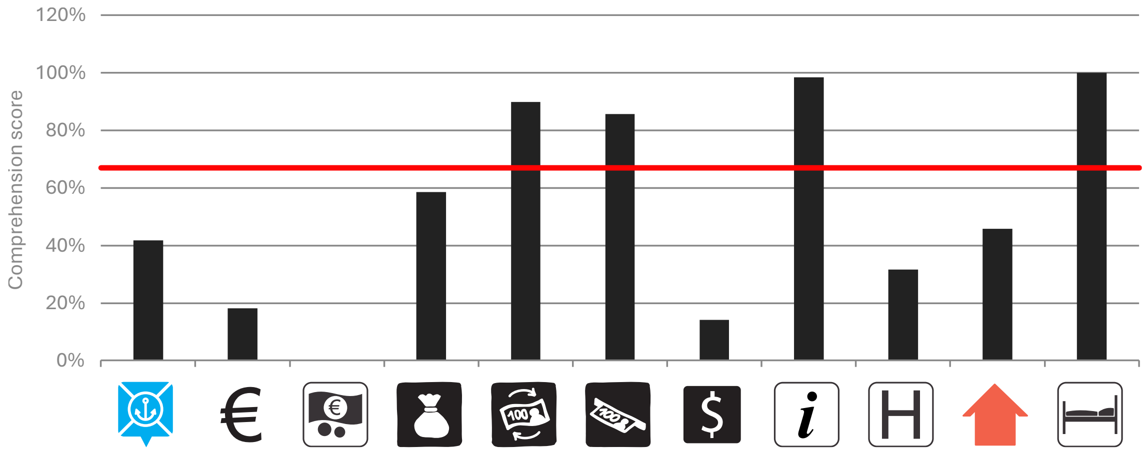


Figure 4.1 Distribution of the correct interpretations of the pictograms (from left to right: anchorage; ATM; ticket sale; bank; exchange office; ATM; ATM; information office; hotel; mountain lodge; accommodation). The red line indicates a 67% minimum criterion for successful interpretation (reproduced from Cibilić and Poslončec-Petrić, 2025)

To better understand how these misinterpretations occurred, the open-ended answers were grouped into broader thematic categories (e.g., hotel, hostel, and motel grouped as "accommodation"), allowing comparison between intended meanings and participants' interpretations. Open-ended responses were coded using the procedure described in Section 3.4. Demographic comparisons were explored descriptively (age and gender), but no meaningful differences emerged across these variables, so they were not emphasised in further reporting. Instead, the results are presented through overall interpretation patterns, supported by differences between experienced and non-experienced map users where relevant.

The next question concerned assigning the correct meaning to the presented symbol. For the pictogram intended to represent anchorage, 42% of participants answered correctly, while almost the same proportion interpreted it as port (40%); a small proportion did not answer. Interestingly, non-experienced users selected the correct interpretation slightly more often (n = 30) than experienced users (n = 25) (Figure 4.2). In this case, language may have played a role: terms such as "anchorage" may not be equally familiar to all respondents, potentially influencing the pattern of responses.

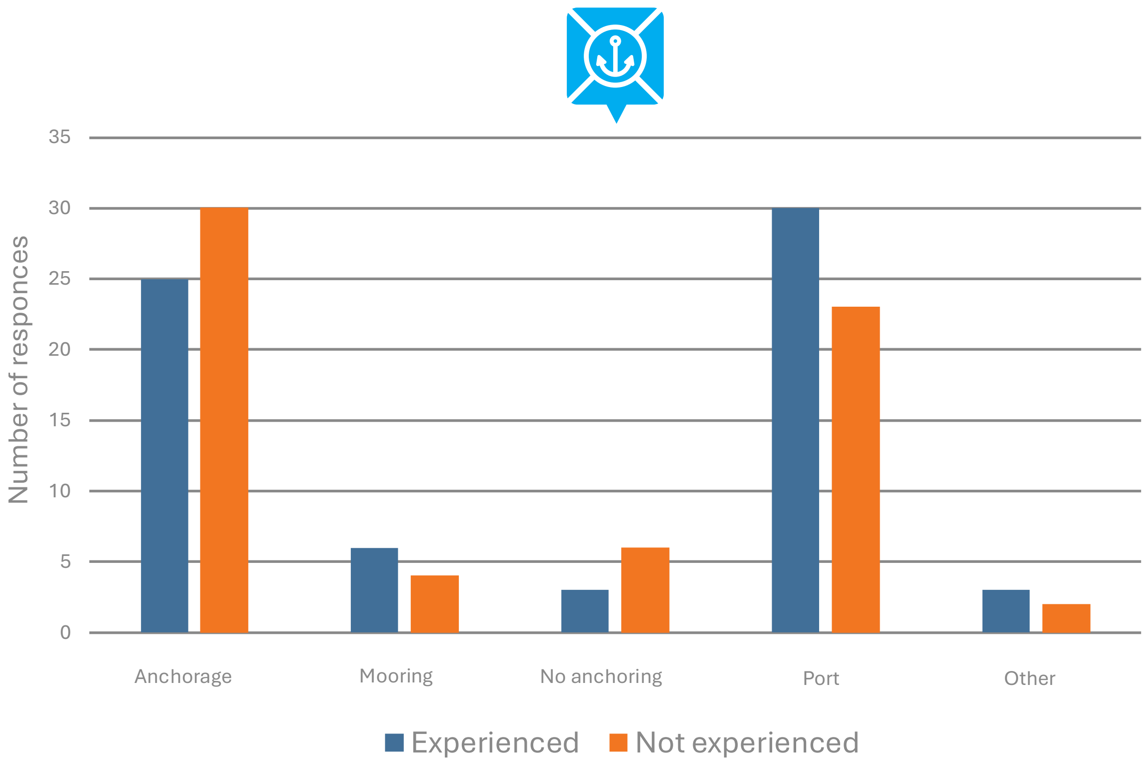


Figure 4.2 Distribution of answers for symbol meaning derived from Brijuni National Park map (reproduced from Cibilić and Poslončec-Petrić, 2025)

A greater degree of ambiguity was observed in the next closed question, where the euro sign was used to indicate an ATM. Only 18% of participants correctly identified the intended meaning, while many interpreted it with a broad, non-specific "money" description (33%). As "money" conveys a general, non-specific financial meaning rather than a clearly defined POI type, these responses were treated as generic interpretations rather than correct identifications of the intended "ATM" symbol. Among the remaining answers, 30% of participants thought it represented an exchange office, 9% indicated it as a bank, and 10% of responses were vague or unclear. Notably, correct identification was higher among experienced map users (n=17) than among non-experienced users (n=7), suggesting that this symbol may depend more on cartographic familiarity than on intuitive visual encoding.

The following question presented a set of five black-and-white pictograms related to financial services (Figure 4.3). Participants were asked to provide the meaning of each symbol in an open-ended format. Response rates for this set were relatively consistent, with approximately 70% of participants answering each item (73%, 73%, 74%, 74%, and 70%, respectively), and no meaningful differences were observed between experienced and non-experienced map users.

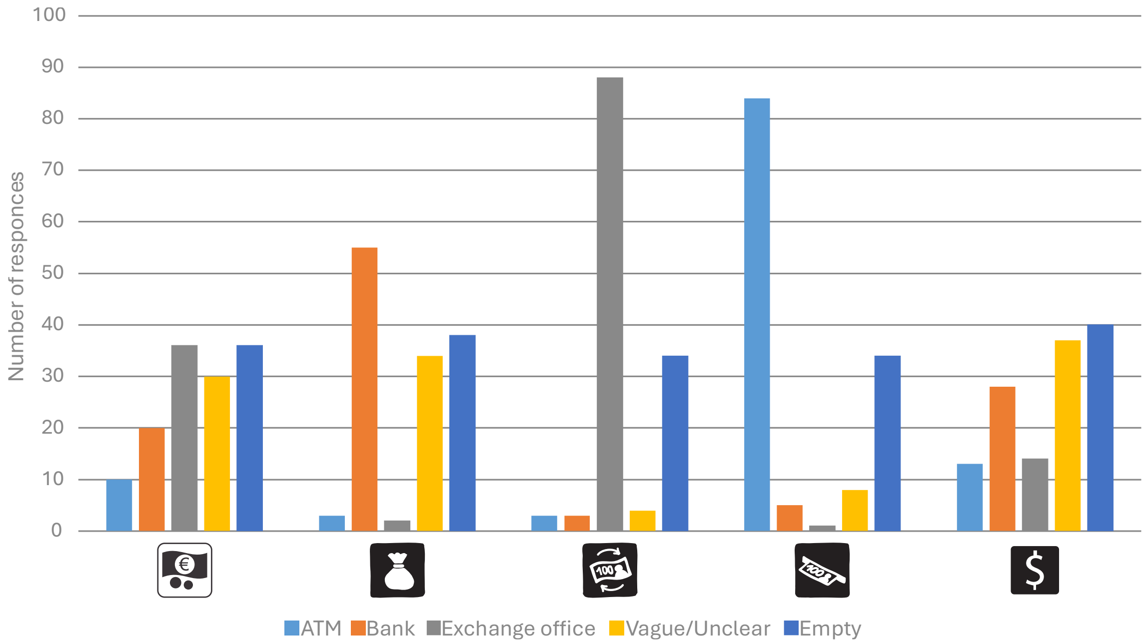


Figure 4.3 Distribution of answers for financial pictograms (from left to right: ticket sales; bank; exchange office; ATM; ATM) (reproduced from Cibilić and Poslončec-Petrić, 2025)

The first pictogram in the set was intended to represent a ticket sales office, but none of the participants answered correctly. Instead, responses most often shifted towards other financially related categories, most commonly exchange office (n = 36), followed by vague or unclear answers (n = 30), bank (n = 20), and ATM (n = 10). Here, “vague/unclear” refers to responses that describe the visual form of the pictogram rather than its intended function, or that use broad, non-specific terms that cannot be reliably linked to a single POI category (e.g., “money bag”, “safety”, “vault”, “treasure”). Three of the remaining symbols in the set were taken from the same Plitvice Lakes National Park map. The second pictogram was interpreted correctly as a bank by 59% of responses, but a substantial share of answers (36%) fell into the vague or unclear category, often reflecting descriptive rather than functional interpretations. Notably, several of these vague responses were semantically close to the intended meaning (e.g., money, coins, saving), but were coded as vague because they described the concept or appearance rather than explicitly naming the POI type. The third pictogram, indicating exchange office, showed strong performance, with 90% correct interpretations. The fourth pictogram (intended as ATM) was also interpreted correctly by most participants (n = 84). In contrast, the final pictogram – also intended to represent an ATM – produced more mixed outcomes: it had the lowest response rate (70%), and 40% of the answers were vague or unclear, while the remaining responses were split mainly between bank (30%), exchange office (15%), and ATM (14%).

The next item tested a pictogram featuring a small letter “i” at its centre. This symbol was included because it appears widely on tourist maps, yet it is not always used consistently and can be assigned different meanings depending on the map. The question was closed-ended, offering four response options. In this case, interpretation was highly accurate: 98% of participants selected the intended meaning, while the remaining 2% chose “reception”; these incorrect responses occurred only among non-experienced participants. This result indicates that widely conventionalised tourist symbols can remain highly effective across diverse users, even when other, less standardised pictograms perform poorly.

The final comprehension task presented three pictograms related to accommodation (Table 4.2) and used an open-ended format, resulting in a wide range of responses. Response rates were 84% for the first symbol, 80% for the second, and 76% for the third. The first pictogram was intended to represent a hotel, yet only 27% of responses matched this meaning. Instead, half of the participants (50%) interpreted it as a hospital, and this misinterpretation occurred mainly among non-experienced respondents (56% of the “hospital” answers came from the non-experienced group). In contrast, the intended “hotel” meaning was more often provided by experienced participants (n = 22). The second symbol was intended to represent a mountain lodge; 41% of responses indicated direction as the symbol meaning, while only 36% of answers were categorised as accommodation-related (either a specific accommodation type or a general “accommodation” meaning). Here, experience again appeared to matter: experienced participants tended to interpret the symbol within the accommodation domain, whereas non-experienced participants more often assigned a directional meaning. The third pictogram represented a broader concept - accommodation. Only 34% of responses used that exact term, but most answers still fell within the intended category by referring to specific accommodation types (e.g., hotel, apartment, rooms to rent). Taken together, these findings show that accommodation symbols can easily trigger visually plausible alternatives, particularly when the pictogram resembles more common public-service iconography.

Table 4.2 Categories of accommodation and number of responses per category (reproduced from Cibilić and Poslončec-Petrić, 2025)

	Category	Experienced	Not Experienced	Total
	Hospital	29	37	66
	Hostel	0	3	3
	Hotel	22	13	35
	Other	4	1	5
	Vague/Unclear	2	0	2
	Accommodation	28	20	48
	Direction	25	29	54
	Other	2	1	3
	Apartment	5	6	11
	Hotel	15	10	25
	Rooms to rent	5	14	19
	Accommodation (general)	23	22	45

Overall, the pictogram comprehension results indicate that interpretability is inconsistent across the symbol set currently used on Croatian national park maps. Some pictograms function well because they align with established conventions (e.g., information pictogram), while others cause systematic confusion – either between closely related POI categories (e.g., ATM, exchange office, bank) or between visually similar but semantically different concepts (e.g., hotel, hospital). Taken together, these results show that several pictograms were not interpreted reliably across participants, suggesting that current symbol designs are not consistently intuitive and should be improved to support clear use on tourist maps.

4.2.2 User priorities for map content

The final two questions explored user preferences for map content by asking participants, in an open-ended format, to list the objects they consider most important and least important on a tourist map. In total, participants mentioned 1320 objects for the "most important" question and 396 objects for the "least important" question. Because participants listed different numbers of objects and in varying orders, the analysis considered not only how often an object was mentioned, but also how early it appeared in a participant's list. The underlying assumption was that items named first are the most salient to the participant and therefore reflect higher personal priority than items listed later. To reflect this, a weighted-score approach was applied: earlier mentions received greater weight than later ones, producing a measure that reflects both how often an object was mentioned and how highly it was prioritised within individual lists (Griffith and Headley, 1997).

For analysis and reporting, objects were grouped into broad content categories typically found on tourist maps: accommodation, food and beverage, shopping, financial institutions, transport, health services, leisure activities, tourism activities, and public services. These categories followed the same logic and structure as the previous pictogram comprehension analysis. Some objects were mentioned so frequently that they were treated separately (e.g., restrooms within the "most important" responses). A "current location/you are here" concept was also tracked as its own category. Table 4.3 summarises the results for the most important objects by category and participant experience group; it should be noted that the experienced/non-experienced split is shown descriptively, but weighted scores were calculated across the full sample rather than separately by experience.

Table 4.3 Results for most important objects on tourist maps (adapted from Cibilić and Poslončec-Petrić, 2025)

	Experienced	Not Experienced	Count	Weighted Scores
Tourism activities	58	50	108	861
Transport	45	31	76	576
Food and beverage	37	34	71	563
Restrooms	16	21	37	312
Accommodation	20	13	33	275
Financial institutions	20	14	34	272
Other	11	13	24	177
Leisure activities	14	7	21	173
Shopping	7	11	18	135
Health services	8	7	15	121
Location ("You are here")	4	2	6	55

Table 4.3 shows a consistent priority pattern among participants. Both experienced and non-experienced users most frequently highlighted "Tourism activities" (Count = 108; Weighted score = 861), followed by "Transport" (76; 576) and "Food and beverage" (71; 563). "Restrooms" also ranked highly (37; 312), suggesting that basic amenities are considered essential even if not mentioned by everyone. "Accommodation" (33; 275) and "Financial institutions" (34; 272) occupied a similar mid-priority level, while "Leisure activities", "Shopping", and "Health services" were mentioned less often and tended to appear lower in participants' lists. Overall, the categories with the highest weighted scores also had the highest counts, indicating that they were not only frequently mentioned but were often placed in top positions (i.e., treated as higher priority). These findings suggest that tourist maps should clearly emphasise core needs – attractions/activities, movement through the park, and basic services – while treating other categories as secondary, depending on the map's purpose and available space.

Table 4.4 presents the responses to the "least important" question, again grouped by content categories and experience level. Here, the category structure differs slightly from the "most important" analysis because it reflects how participants framed low-priority content; in this section, restrooms were included within the public services category.

Table 4.4 Results for least important objects on tourist maps (reproduced from Cibilić and Poslončec-Petrić, 2025)

	Experienced	Not Experienced	Count	Weighted Scores
Public services	15	15	30	81
Food and beverage	6	10	16	44
Tourism activities	7	6	13	38
Leisure activities	3	7	10	27
Financial institutions	6	3	9	26
Accommodation	7	2	9	25
Transport	3	5	8	21
Other	4	3	7	21
Shopping	5	1	6	18
Health services	2	2	4	11

For the least important objects on a map, "Public services" ranked highest (Count = 30; Weighted score = 81), with this distributed equally between experienced and non-experienced participants (15 each). This pattern suggests that, while public services are recognised, many participants do not consider them central to the immediate tourist map experience. "Food and beverage" also appeared relatively often among low-priority selections (16; 44), which may indicate that some users treat food-related information as secondary or assume it can be accessed through other sources. A small divergence emerged for "Leisure activities", which were more frequently selected as low priority by non-experienced participants (7) than by experienced participants (3). Other categories – such as "Transport", "Accommodation" and "Financial institutions" – also appeared among low-priority selections, alongside "Shopping" and "Health services", which generally attracted limited attention.

To translate these priorities, the object categories were ranked using the composite overall weighted score, as shown in Table 4.5. The results show a clear separation between the three highest-ranked categories - tourism activities, transport, and food and beverage - and the remaining categories, indicating that participants prioritised these categories most strongly in their content expectations for tourist maps.

Table 4.5 Composite table of weighted scores for object-category importance.

	Weighted score (most important)	Weighted score (least important)	Composite weighted score
Tourism activities	861	38	823
Transport	576	21	555
Food and beverage	563	44	519
Accommodation	275	25	250
Financial institutions	272	26	246
Public services	312	81	231
Other	177	21	156
Leisure activities	173	27	146
Shopping	135	18	117
Health services	121	11	110
Location ("You are here")	55	0	55

4.2.3 Summary and design implications

Taken together, the Phase 2 findings highlighted two complementary design needs. First, the pictogram analysis showed that several symbols currently used on Croatian national park maps were not interpreted reliably without legend support, despite pictograms being intended as language-independent cues understandable to occasional users. This suggests that some symbols are not intuitive enough and may make the maps harder to understand. Second, the needs-assessment questions clarified what users want emphasised on tourist maps. Tourism activities emerged as the most important object category (highest overall weighted score), followed by "Transport" and "Food and beverage", while "Public services" were more often treated as low priority. Together, these findings provided a concrete basis for Phase 3 by clarifying which content categories users prioritise and which pictograms are least reliably interpreted without legend support.

4.3 Phase 3 Results – Conceptual design and AR prototyping

Phase 3 translated the key findings from the competitive analysis of existing national park maps (Phase 1) and the user needs assessment (Phase 2) into two comparable map prototypes: a traditional analogue tourist map and an augmented map presented through a handheld mobile AR interface. The aim of this phase was to develop two controlled test stimuli that operationalise the thesis design concept, particularly the separation of tourist information between a printed base map and a virtual overlay to reduce visual clutter and support clearer placement of point symbols. The first-iteration versions created in this phase served as the basis for the expert review in Phase 4. Following expert feedback, both the analogue and augmented prototypes were refined and finalised for the usability evaluation in Phase 5.

The Phase 2 results served as a practical guide for determining the content of the Phase 3 prototypes. Instead of attempting to replicate the full and often inconsistent range of content found on existing national park maps, the prototypes were based on a controlled set of object categories that reflected users' expectations while maintaining map readability and comparability. To establish a clear inclusion rule from the overall ranking, the categories were grouped into three equal-frequency tiers (quantiles). All categories in the highest tier were retained, and one representative category was selected from each of the two lower tiers. This resulted in five included categories: tourism activities, transport, food and beverage, public services, and shopping. The specific objects selected from each category are summarised in Table 4.6.

Table 4.6 Category selection for the map prototypes derived from Phase 2 priorities.

Priority tier (quantile group)	Category	Composite weighted score	Included in prototypes	POIs used
Tier 1 (highest)	Tourism activities	823	Yes	information point; waterfalls
	Transport	555	Yes	parking lot; boat harbour
	Food and beverage	519	Yes	restaurant; coffee shop
Tier 2 (middle)	Accommodation	250	No	—
	Financial institutions	246	No	—
	Public services	231	Yes	toilet (v1) / viewpoint (v2)
Tier 3 (lower)	Leisure activities	146	No	—
	Shopping	117	Yes	souvenir shop
	Health services	110	No	—
	Location ('You are here')	55	No	—

Note: In the refined version used in Phase 5, the toilet pictogram in the initial prototype was replaced with a viewpoint pictogram; this change did not alter the total POI counts.

This step defined the final content set included in both prototypes. The total number of objects was kept constant between the two stimuli, while the augmented condition divided objects between the printed base map and the AR overlay layer (see section 3.6, Table 3.2).

The prototypes were designed as a matched pair so that the pictogram set, POI categories, scale, layout logic, and overall content density remained consistent across conditions. This controlled approach ensured that subsequent differences in user performance could be attributed primarily to the presentation mode (paper-only versus paper plus virtual overlay) and the distribution of POIs across layers, rather than to inconsistent symbol design or content scope. To avoid the symbol variability identified in Phase 1, a standardised pictogram set aligned with national-level guidelines was adopted (used with permission).

Both stimuli were designed as fictional but realistic park environments to minimise familiarity effects and support controlled testing. The analogue stimulus was produced as a print-ready tourist map (Figure 4.4), while the AM stimulus consisted of a corresponding printed base map used for tracking (Figure 4.5), combined with a marker-based AR overlay displaying the remaining objects as virtual pictograms aligned with the map surface (Figure 4.6). The prototype was intentionally kept simple, using static 2D pictogram overlays, to ensure that the comparison in later phases focused on the cartographic layering concept rather than interaction complexity.

Before proceeding to the expert review, the materials were checked for basic print legibility and symbol consistency, as well as stable marker detection and acceptable alignment of the virtual overlay under typical indoor lighting. Following Phase 4, both the analogue and augmented stimuli were refined and used in Phase 5; the specific expert-identified issues and resulting changes are reported in the Phase 4 results.

Figure 4.4 shows the analogue stimulus, demonstrating the symbol hierarchy and density used as the control condition. Figure 4.5 shows the printed base map prepared for the augmented condition, illustrating the same cartographic design logic while serving as the physical tracking surface for the AM prototype. Figure 4.6 shows the AM overview, demonstrating how the remaining POIs were visualised as a virtual overlay and aligned with the printed map to operationalise the layering concept tested in the subsequent phases.

Figure 4.4 Analogue map stimulus used in Phase 4

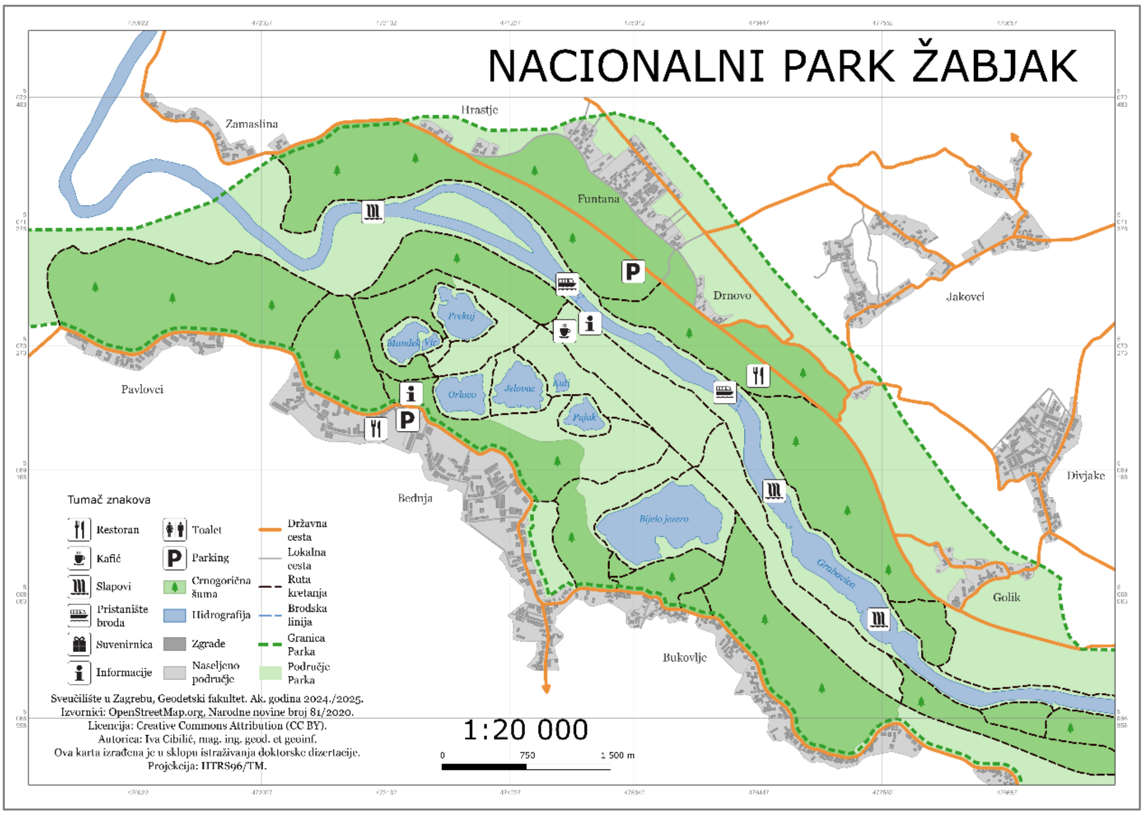


Figure 4.5 Augmented map stimulus-printed base layer used in Phase 4

Figure 4.6 Augmented map overlay view used in Phase 4 (screenshot)

4.4 Phase 4 Results – Expert cartographic review and formative refinement

Phase 4 involved a formative expert review of the developed analogue and augmented map prototypes, serving as the final refinement step before the user-based usability evaluation (Phase 5). Seven experienced cartographers assessed both stimuli in individual sessions, focusing on usability, cartographic quality, and cognitive load. As the two conditions were reviewed in parallel, they were able to comment directly on differences between the analogue and augmented stimuli. The aim of this phase was to identify cartographic, perceptual, and interaction issues early, and to use expert recommendations to refine both the map stimuli and the planned user-testing protocol before the final usability study in Phase 5.

4.4.1 Overview of expert feedback

Expert feedback was audio- and video-recorded. Experts were encouraged to ask questions and describe their observations and reasoning. Although the sessions followed a think-aloud approach, the "keep talking" prompt was not used, and experts were not required to verbalise their interactions. The recordings were reviewed to complement the written notes, add missing details, and ensure that comments were captured consistently across sessions.

All comments were then merged into a refinement log by grouping repeated observations into shared issues and translating them into concrete design actions. Each item was tagged by (a) which stimulus it referred to (analogue vs. augmented condition), (b) the main focus of the comment (usability, cartographic principles, or cognitive load), and (c) the number of experts who mentioned it. Ambiguous cases were discussed with the supervisor, and the agreed list was implemented as the final refinement of both stimuli. This approach followed common practice in expert-based, formative map evaluation, where reporting emphasises traceable design decisions rather than performance metrics (Roth et al., 2015).

At a general level, experts reported that both maps were readable at first glance and that the pictograms were easy to interpret. Orientation cues and scale were also evaluated positively. However, several comments highlighted gaps and inconsistencies, such as the missing north indicator, the placement of the main direction arrows, and the definition of the map extent; these could create uncertainty for first-time users in both conditions. These points guided the prioritisation of refinements reported below, focusing on changes that (a) stabilise the core AM concept, (b) reduce ambiguity that could affect Phase 5 measurement, and (c) preserve comparability between the two stimuli.

4.4.2 Identified issues and refinements

Focusing on the AM concept, all experts agreed on one key point: the map's augmented nature should be made more obvious. To address this, a brief onboarding note was added to the printed AR base map to explicitly indicate that additional content becomes visible when the phone is pointed at the map. All experts described this as essential for first-time users, who might otherwise treat the map as a conventional analogue map or feel uncertain about what they are expected to do.

A second consistent recommendation was to remove virtual pictograms from the printed legend and present them through a fixed on-screen virtual legend. This change strengthened the intended distinction between printed and virtual layers: the printed legend now includes only symbols that exist in print, while the virtual legend contains only symbols that appear virtually. In practical terms, this reduces the likelihood that users search for virtual content in the printed legend or assume a printed symbol should exist simply because it is listed and helps the virtual overlay feel immediately interpretable during use. Because this AM concept is based on reducing clutter by moving selected POIs into a virtual layer, the dual-legend solution was considered as a core design decision.

Several refinements improved local legibility and the spatial association of pictograms. In the analogue stimulus, four of seven experts commented on the presentation of grouped pictograms and suggested a more conventional cartographic approach: bringing the symbols closer together and enclosing them within a clear boundary to indicate that they form a single cluster. Experts also noted that overlaps between pictograms and background layers should be avoided, as even minor conflicts can reduce clarity and introduce unnecessary search effort. In the AM condition, one expert observed that some pictograms intended to represent objects along the walking route were positioned too far from the route, weakening their intended meaning; these were repositioned to strengthen the route–object relationship. Finally, the virtual content set was refined by replacing the toilet pictogram with a viewpoint pictogram, reflecting experts' view that, in this context, prioritising more tourism-oriented POIs is more meaningful, and that in the AM condition, the augmented layer should be reserved for information that adds clearer interpretive value beyond what users typically expect to find on the printed map.

A recurring discussion point was that some experts expected more interaction with the virtual elements, such as toggling layers or selecting objects for additional details. This was considered an important implication, but it was not implemented in this thesis. Adding interaction would introduce a second independent variable and weaken the controlled comparison planned for Phase 5. Instead, the AM was intentionally kept minimal in terms of interaction so that Phase 5 could isolate the effect of dividing information between the printed and virtual layers, rather than differences in interaction design. This approach aligns with cognitive cartography literature, which indicates that dynamic and interactive map behaviour can alter users' cognitive processing and increase cognitive load (Griffin et al., 2024; Ooms et al., 2012, 2015). In this way, experimental control was retained while still identifying a clear direction for future AM iterations.

Expert feedback also led to a targeted refinement of the Phase 5 protocol: the distance-comparison tasks were revised to specify "distance via the path" rather than allowing interpretation as straight-line distance. This change was made to remove ambiguity and support more consistent measurement across participants and conditions. For the remaining tasks and the protocol overall, experts considered them realistic, appropriately challenging, and suitable for revealing usability issues.

Table 4.7 summarises the prioritised refinements and their implementation status, while the complete refinement log, including minor cartographic corrections and all implementation decisions, is provided in Appendix D. Importantly, refinements focused on clarity and interpretability rather than altering the controlled content structure established in Phase 3. This preserved the intended comparison in Phase 5 and reduced avoidable sources of error.

Table 4.7 Summary of prioritised expert-led refinements

	Refinement (priority)	**Implemented?**	**Applies to**	**Experts mentioning**
1.	Add a note to the printed AR base map explaining that additional content becomes visible when the device is pointed at the map.	Yes	AM condition	7/7
2.	Separate printed and virtual symbols using a dual-legend approach: keep printed symbols in the paper legend and move virtual symbols to a fixed on-screen virtual legend.	Yes	AM condition	7/7
3.	Reposition selected POIs to strengthen route-based association, so that symbols intended to represent objects “along the trail” are spatially read in relation to the walking route.	Yes	AM condition	4/7
4.	Implement AR interaction (e.g., layer toggles or object selection for details)	No	AM condition	4/7
5.	Reduce local ambiguity by eliminating overlaps between pictograms and background layers.	Yes	Both	4/7
6.	Improve the readability of clustered POIs (e.g., tighter grouping and a clear grouping boundary).	Yes	Analogue condition	3/7
7.	Strengthen basic orientation support by adding a north indicator and simplifying scale presentation (removing the numerical scale and extending the linear scale).	Yes	Both	7/7
8.	Improve direction cues by refining arrow logic (pointing main directions) and ensuring that the full park extent is visible.	Yes	Both	6/7
9.	Refine the POI content set by replacing the toilet pictogram with a viewpoint pictogram.	Yes	Both	5/7
10.	Clarify Phase 5 task wording so that distance comparisons explicitly refer to distance along the path/trail, rather than straight-line distance.	Yes	Phase 5 protocol	1/7

Overall, Phase 4 served as a formative quality check that enhanced the clarity and robustness of both stimuli while maintaining the controlled design logic established in Phase 3. The expert review also strengthened the Phase 5 protocol by improving task wording and ensuring the task set was realistic and capable of identifying usability issues across both the analogue and AM conditions. The refined stimuli and finalised task protocol were then carried forward into Phase 5 for comparative usability evaluation. Figures 4.7 – 4.9 show the refined map stimuli used in the final research phase: user-based usability evaluation.

Figure 4.7 Final analogue map stimulus

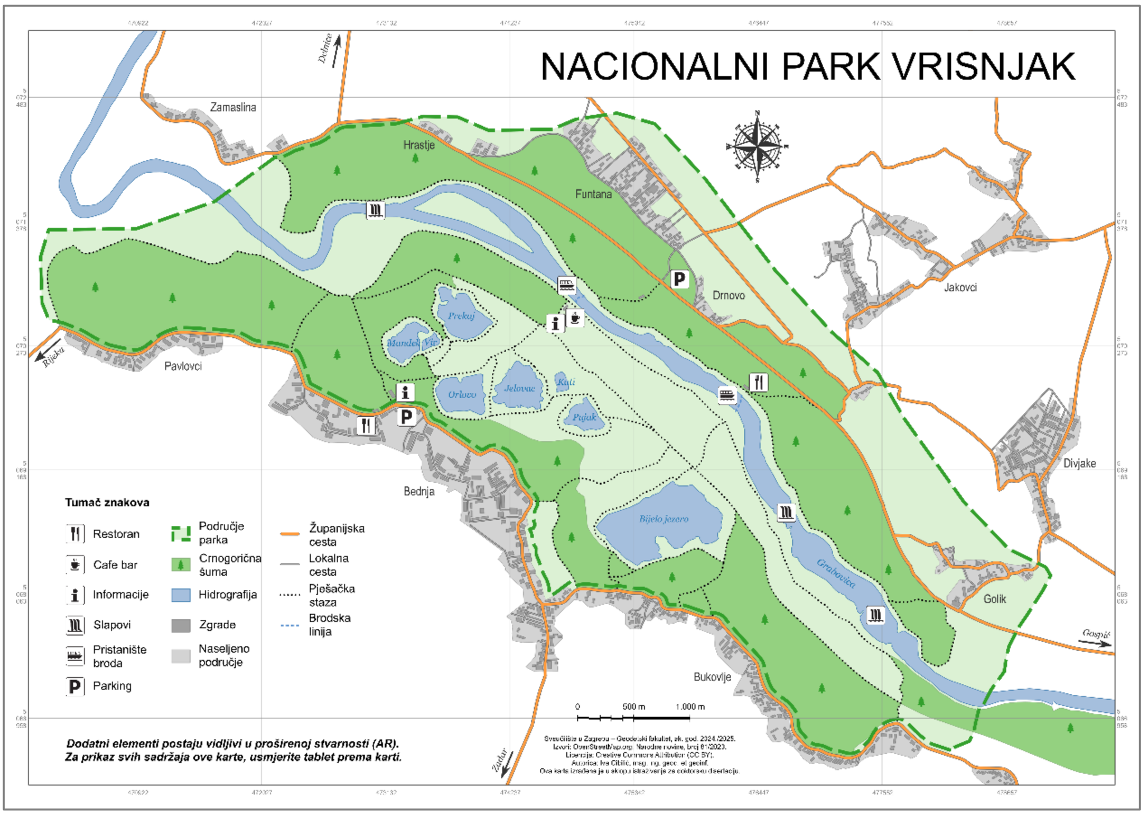


Figure 4.8 Final augmented map stimulus-printed base layer

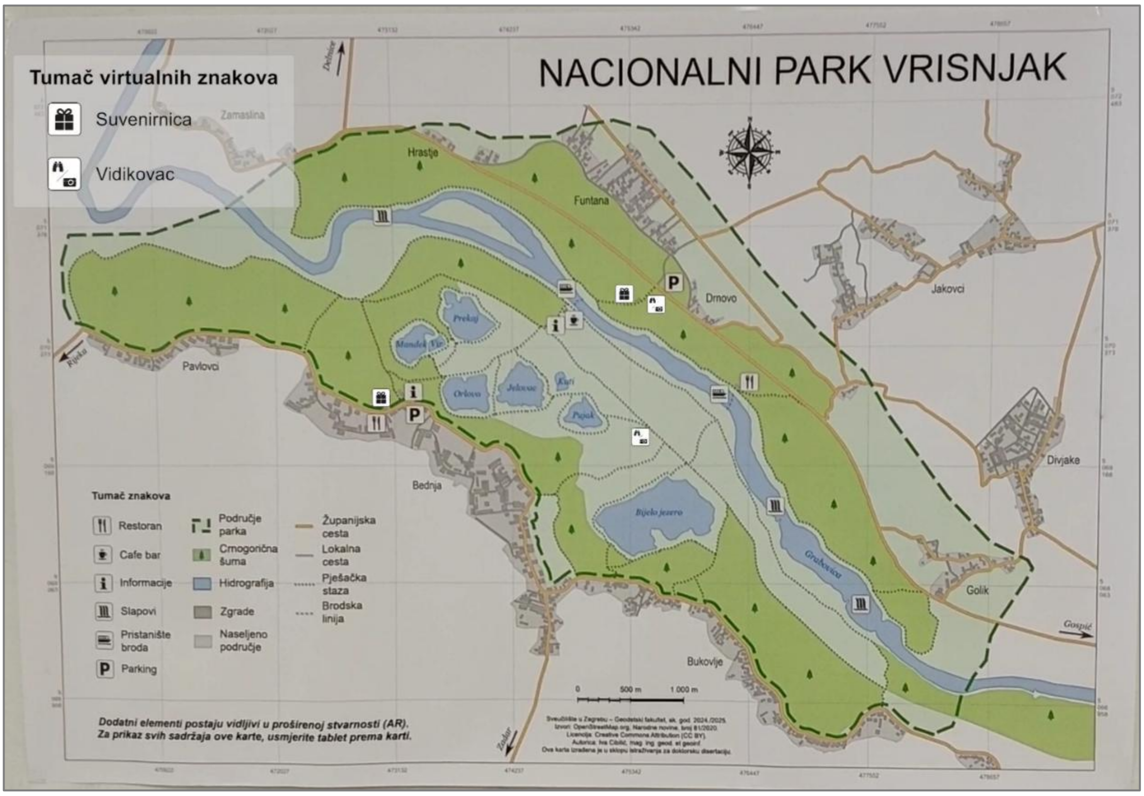


Figure 4.9 Final augmented map overlay view (screenshot)

4.5 Phase 5 Results – User-based usability evaluation

Phase 5 provided the main comparative usability evaluation of the two refined map conditions: the analogue map and the augmented map. The purpose of this phase was to test whether the augmented map supports users in completing typical tourist-map tasks effectively and efficiently, compared to a conventional analogue map as benchmark. Outcomes are reported for the three main usability dimensions: effectiveness (task success), efficiency (completion time), and subjective usability satisfaction (SUS and post-test ratings). As the study used a within-subjects design with counterbalanced map order, all comparisons reported below reflect paired analysis between the same participants across conditions. In accordance with the distributional characteristics of the measures, non-parametric paired tests were used for the main comparisons (Wilcoxon signed-rank for continuous outcomes; McNemar for paired binary task-success comparisons at the task level).

4.5.1 Effectiveness (task success)

Effectiveness was assessed as task success (correct/incorrect) and summarised as overall success rate per condition, and task-level success rates.

Overall success was high in both conditions; participants correctly completed an average of 81% of tasks on the analogue map (95% CI: 75.3%–86.5%) and 84% of tasks on the augmented map (95% CI: 77.6%–91.1%).

Because the paired accuracy differences were non-normally distributed (Shapiro–Wilk $p = 0.013$), the overall comparison was performed using a paired Wilcoxon signed-rank test. No statistically significant difference was found in overall effectiveness between the analogue and augmented map conditions ($V = 198.5$, $p = 0.218$). The effect size was small ($r = 0.15$), suggesting only a slight advantage for the augmented map, but this difference was not statistically significant.

This pattern was also evident at the participant level: 18 participants achieved higher overall success with the augmented map, 14 performed better with the analogue map, and 16 achieved identical scores, suggesting that any advantage of augmentation in task success was small and not consistent across users.

To determine whether effectiveness differences were concentrated in particular task types, task-level success was compared between the two map conditions using McNemar's tests; results are summarised in Table 4.8. Given the number of task-level comparisons, these results are reported as exploratory (unadjusted p-values). It should be noted that Task 1 is reported as a baseline symbol-comprehension check rather than a condition effect, as it was completed in the same manner in both conditions; therefore, its results primarily reflect pictogram understanding rather than differences between map conditions.

Table 4.8 Task-level success rates by task type for the analogue and augmented map conditions with significance indicators

Task no.	Task type	Analogue map % Correct	Augmented map % Correct	McNemar's χ^2	p-value
1	Sign interpretation	96%	92%	0.17	0.683
2	POI search	94%	88%	0.80	0.371
3	Distance comparison	65%	71%	0.17	0.676
4	Navigation from start point	100%	81%	**7.11**	**0.007**
5	Shortest route (navigation/planning)	81%	90%	0.90	0.342
6	Distance comparison	50%	85%	**9.48**	**0.002**

Most tasks showed comparable success rates across conditions (Table 4.8). Statistically significant differences were observed for Task 4 and Task 6 (Task 4: $\chi^2 = 7.11$, $p = 0.007$; Task 6: $\chi^2 = 9.48$, $p = 0.002$). Task 4 favoured the analogue condition, while Task 6 favoured the augmented condition. Figure 4.10 shows task-level success rates by condition.

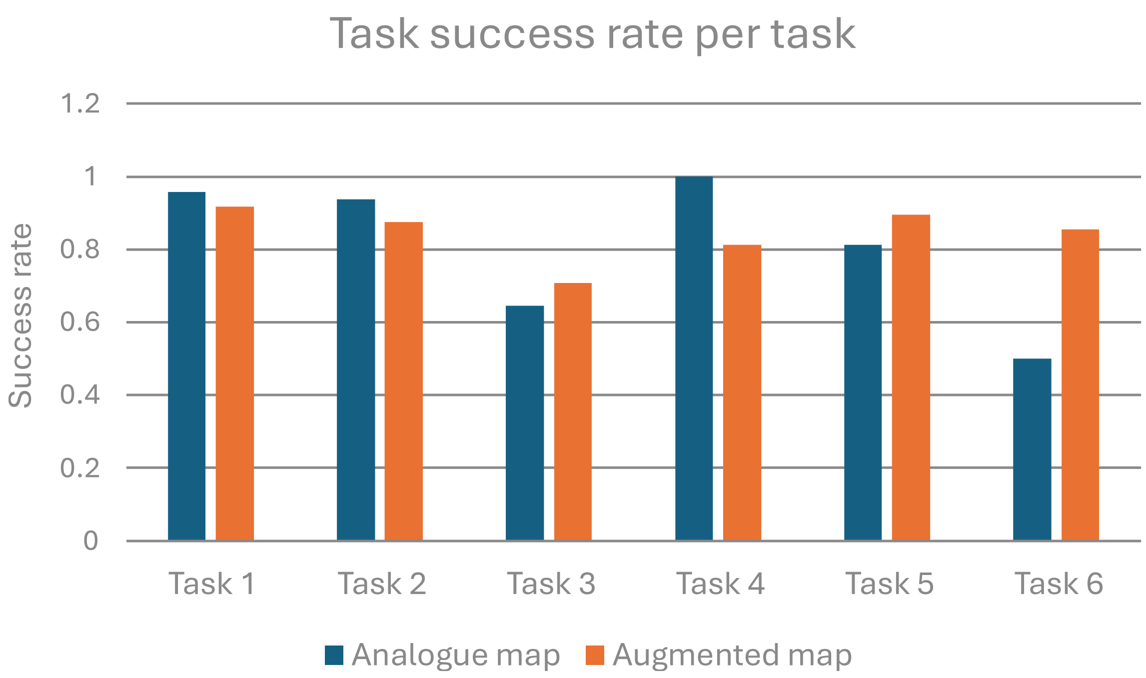


Figure 4.10 Task-level success rates for the analogue and augmented map conditions

Taken together, the task-level results suggest that augmentation did not uniformly affect effectiveness across tasks, but produced clear task-specific effects, improving success in Task 6 while reducing success in Task 4. Accordingly, hypotheses related to task success (H5.1 and H5.2) were only partially supported in terms of effectiveness, as the augmented condition improved success for one search/comparison task (Task 6) but did not yield consistent advantages for navigation and planning tasks.

4.5.2 Efficiency (completion time)

Efficiency was measured as completion time and summarised per participant as the mean time per task across the six tasks for each map. Participants were faster with the augmented map ($M = 7.61$ s, $SD = 3.84$, 95% CI [6.53, 8.70]) than with the analogue map ($M = 10.56$ s, $SD = 4.97$, 95% CI [9.16, 11.97]) (Table 4.9). Because the paired time differences were non-normally distributed, a paired Wilcoxon signed-rank test was used and showed a statistically significant difference in completion time between map conditions ($V = 1029.5$, $p = 8.61 \times 10^{-7}$) with a large effect size ($r = 0.71$), indicating a substantial overall efficiency advantage for the augmented map.

Table 4.9 Overall completion time per participant for the analogue and augmented map conditions, reported for all attempts and for correct answers only

	Analogue map			Augmented map		
	Mean Time [s]	**Standard Deviation**	**95% Confidence Intervals**	**Mean Time [s]**	**Standard Deviation**	**95% Confidence Intervals**
All answers	10.56	4.97	[9.16, 11.97]	7.61	3.84	[6.53, 8.70]
Correct answers	10.49	5.37	[8.97, 12.01]	7.57	4.41	[6.32, 8.82]

To align efficiency with successful completion, completion time was also computed as the mean time per correct task (averaging only those task times where the participant responded correctly) (Table 4.9). This correct-only metric again favoured the augmented map (M = 7.57 s, SD = 4.41, 95% CI [6.32, 8.82]) over the analogue map (M = 10.49 s, SD = 5.37, 95% CI [8.97, 12.01]); the paired Wilcoxon test confirmed a statistically significant difference (V = 995.5, p = 2.984e−05) with a large effect (r = 0.60). Figure 4.11 illustrates participant-level mean completion times across the two map conditions.

The direction of this result was consistent, with 73% of participants completing the tasks faster in the augmented condition than in the analogue condition.

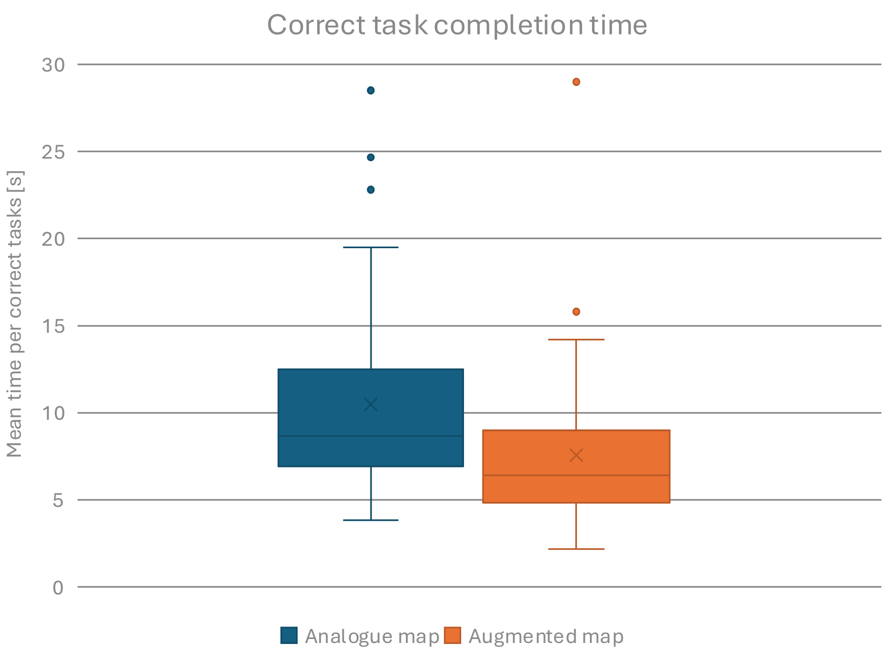


Figure 4.11 Participant-level mean completion times across the two map conditions

To identify where the time advantage emerged, paired completion times were also compared per task using Wilcoxon signed-rank tests. As six task-level tests were conducted, these are reported as exploratory (unadjusted p-values), with Table 4.10 showing the full details.

Table 4.10 Task-level mean completion times for the analogue and augmented map conditions (all attempts), with significance indicators

Task	Mean completion time in analogue map [s]	Mean completion time in augmented map [s]	Wilcoxon V	p-value	Effect size	Magnitude
1	4.06	4.79	408	0.589	0.07	Small
2	11.79	10.42	584	0.456	0.11	Small
3	8.25	5.29	697.5	**0.007**	**0.41**	**Medium**
4	8.67	8.21	494	0.148	0.23	Small
5	22.92	13.92	997.5	**4.54e-06**	**0.66**	**Large**
6	7.69	3.04	778	**7.19e-07**	**0.74**	**Large**

Note: Task types follow the taxonomy shown in Table 4.8.

No significant differences were found for Tasks 1 (sign interpretation), 2 (POI search), and 4 (navigation from start point). Task 3 (distance comparison) was completed significantly faster on the augmented map (Task 3: V = 697.5, p = 0.007, r = 0.41), followed by Task 5 (shortest route) and Task 6 (distance comparison), which showed an even stronger advantage for the augmented map (Task 5: V = 997.5, p = 4.54e−06, r = 0.66; Task 6: V = 778, p = 7.19e−07, r = 0.74).

Overall, the task-level pattern indicates that the augmented map's efficiency gains were concentrated in Tasks 3, 5, and 6, while Tasks 1, 2, and 4 showed no reliable time difference between the two map conditions. Accordingly, the time-based hypotheses (H5.1 and H5.2) were supported for Tasks 3 and 6 and partially supported for navigation and planning, as the augmented condition yielded a clear efficiency advantage for Task 5 but not for Task 4.

4.5.3 Subjective usability and satisfaction (SUS and post-test questions)

Satisfaction was assessed using a combination of a standardised questionnaire and direct post-test questions. Perceived usability was measured with the SUS questionnaire and summarised per participant as it was completed after each map condition. SUS scores were high in both conditions, as shown in Table 4.11. Participants rated the analogue map with an average SUS score of 87.29 (SD = 13.03, 95% CI [83.60, 90.98]) and the augmented map with 89.32 (SD = 11.73, 95% CI [86.00, 92.64]). Because the paired SUS differences were non-normally distributed (Shapiro–Wilk p = 1.411e−05), the overall comparison was performed using a paired Wilcoxon signed-rank test. No statistically significant difference was found in SUS scores between the analogue and augmented map conditions (V = 221, p = 0.289), suggesting that perceived usability was similarly high for both maps.

Table 4.11 System Usability Scale (SUS) scores by map condition and paired comparison

Map	Average SUS score	Standard Deviation	95% Confidence Intervals	Wilcoxon V	p-value	Effect size	Magnitude
Analogue Map	87.29	13.03	[83.60, 90.98]	221	0.289	0.21	Small
Augmented Map	89.32	11.73	[86.00, 92.64]				

Direct satisfaction ratings were collected using two post-test items: "How would you describe your experience of using these maps?" to record overall experience, and "Was one map more intuitive or easier to use?" to capture perceived preference between the two conditions. All participants reported a positive experience (100%). When asked which map was more intuitive or easier to use (second question), responses were mixed: 27% preferred the analogue map (13/48), 25% preferred the augmented map (12/48), and 48% reported no preference (23/48). Taken together, these post-test ratings suggest that, for most participants, both map conditions were perceived as similarly intuitive and easy to use. Accordingly, H5.3 was partially supported: the augmented map was rated at least as usable as the analogue map, but it did not show a clear advantage in perceived usability or preference.

4.5.4 Individual differences and order effects

To support interpretation of the main paired comparisons, additional exploratory checks examined whether results varied by gender, age group, or spatial ability (SBSOD) within each map condition. As these analyses were run separately for each condition, they should be read as contextual evidence rather than formal interaction tests.

For effectiveness, demographic analyses revealed that overall success rates did not differ by gender for either condition (analogue map: Wilcoxon rank-sum W = 241, p = 0.330; augmented map: W = 299.5, p = 0.763). Age-group differences were assessed using Kruskal–Wallis tests; effectiveness did not differ significantly by age group for the analogue map ($\chi^2(5) = 5.47$, p = 0.362), but evidence of differences across age groups was observed for the augmented map ($\chi^2(5) = 12.66$, p = 0.027), with the 25–34 years group showing the highest mean accuracy. Figure 4.12 illustrates overall success rates by age group for each map condition. Spatial ability, as measured by the SBSOD score, was not significantly correlated with effectiveness for either map condition (Spearman $\rho = 0.12$, $p = 0.402$ for the analogue map; $\rho = -0.22$, $p = 0.136$ for the augmented map).

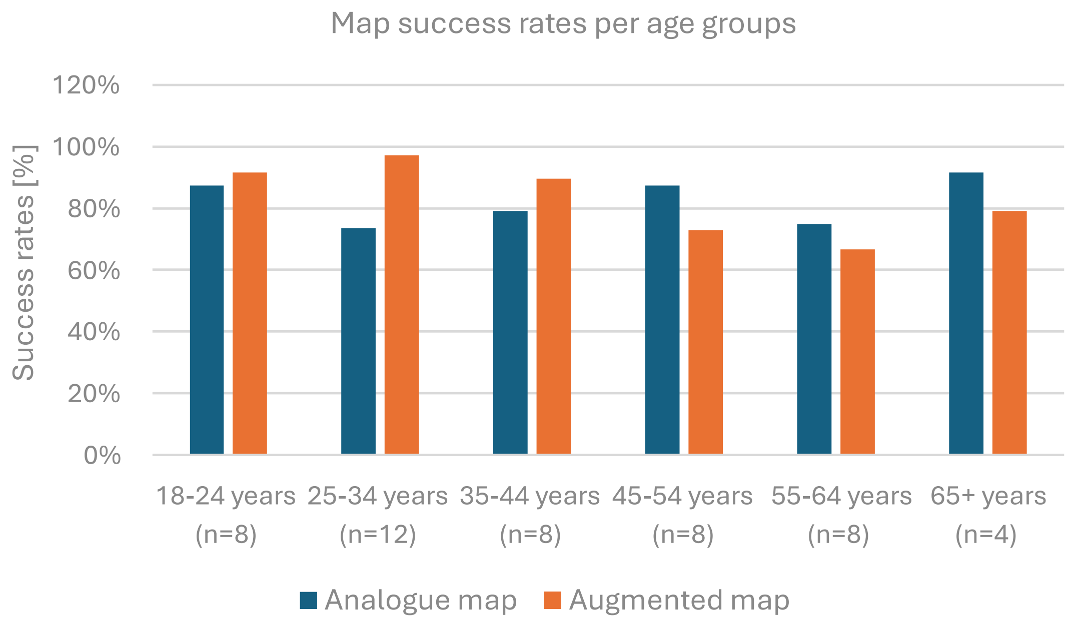


Figure 4.12 Overall success rates by age group for the analogue and augmented map conditions

For efficiency (mean time per correct task), no statistically significant differences were observed by gender (analogue: $p = 0.261$; augmented: $p = 0.227$), and neither age nor SBSOD showed significant associations with correct-only completion time (age: Spearman $\rho = 0.20$, $p = 0.184$ for analogue map; $\rho = 0.24$, $p = 0.097$ for augmented map; SBSOD: Spearman $\rho = 0.19$, $p = 0.204$ for analogue map; $\rho = 0.21$, $p = 0.157$ for augmented map).

For satisfaction, SUS scores were consistently high and showed no systematic differences across participant characteristics in either map condition. In the augmented condition, SUS did not differ by gender (Wilcoxon rank-sum $W = 320$, $p = 0.484$), by age group (Kruskal–Wallis $\chi^2(5) = 3.680$, $p = 0.596$), or by spatial ability (Pearson $r = -0.02$, $p = 0.891$). The same pattern was observed in the analogue condition, where SUS again did not differ by gender (Wilcoxon rank-sum $W = 324$, $p = 0.435$) or by age group (Kruskal–Wallis $\chi^2(5) = 5.359$, $p = 0.374$) and was not significantly associated with spatial ability (Pearson $r = 0.15$, $p = 0.321$).

Taken together, these checks suggest that the main usability patterns of both map stimuli were broadly consistent across demographic groups and levels of self-reported spatial ability within this sample. Accordingly, H5.4 was not supported, as SBSOD scores were not significantly associated with task performance (success or completion time) in either condition.

To assess whether the sequence in which the maps were presented influenced usability outcomes (order effects), participant outcomes were compared between the two presentation sequences (Analogue→Augmented vs Augmented→Analogue). Map order did not influence task accuracy for either map, indicating that effectiveness findings were robust to sequence. However, order effects were observed for analogue map efficiency (participants were faster on the analogue map when it was presented second) and for augmented map perceived usability (SUS scores were higher when the augmented map was experienced second). These metrics are presented in Table 4.12 and Table 4.13.

Table 4.12 Order effects across usability metrics (between-group comparison by presentation sequence)

Metric	Map condition	Wilcoxon rank-sum	p-value	Direction of effect
Effectiveness	Analogue	W = 288.5	1.000	–
Effectiveness	Augmented	W = 261.0	0.540	–
Efficiency	Analogue	W = 155.5	**0.006**	Faster when the analogue map is used second
Efficiency	Augmented	W = 304.5	0.741	–
Satisfaction	Analogue	W = 256.0	0.513	–
Satisfaction	Augmented	W = 162.0	**0.009**	Higher when the augmented map is used second

Table 4.13 Descriptive statistics for significant order effects only

Metric	Map order	Mean	Median
Efficiency (mean time per correct task)	Augmented→Analogue	8.65 s	8.25 s
	Analogue→Augmented	12.32 s	10.75 s
Satisfaction (SUS score)	Augmented→Analogue	86.25	88.75
	Analogue→Augmented	92.40	96.25

4.5.5 Summary of statistical analysis

Taken together, Phase 5 showed that the augmented map did not deliver a uniform improvement. Task success was high in both conditions, and overall effectiveness did not differ significantly between the analogue and augmented maps. At the task level, however, the pattern was more uneven, with the clearest differences seen as reduced success in Task 4 but improved success in Task 6. The strongest and most consistent advantage of augmentation was observed in efficiency: participants completed tasks faster in the augmented condition, both overall and when analysis was restricted to correctly completed trials, with the largest time savings in Tasks 3, 5, and 6. Subjective usability was similarly high for both maps; SUS scores did not differ significantly, and post-test responses indicated positive experiences with no clear consensus that one map was more intuitive. Finally, exploratory checks suggested that this overall pattern was broadly stable across participant characteristics and self-reported spatial ability, and the map order analyses did not change the core interpretation of the paired comparisons.

4.6 Chapter summary

Across Phases 1–5, this chapter shows how the initial review of Croatian national park maps and symbol practices was translated into expert-, theory-, and user-informed design decisions, resulting in two refined map stimuli evaluated through controlled user-based usability testing. The early phases established the foundations: Phase 1 documented practical inconsistencies and recurring design gaps across existing maps, while Phase 2 clarified what users prioritise on tourist maps and evaluated the current pictograms. Building on these inputs, Phase 3 translated the findings into two comparable map conditions, and Phase 4 provided a formative quality check that improved stimulus clarity and strengthened the testing protocol without compromising comparability. Phase 5 then provided the main comparative usability evidence: overall effectiveness was similar between conditions but varied meaningfully by task, efficiency consistently favoured the augmented map, and satisfaction remained high in both conditions. Taken together, these results provide the evidence base for interpreting the contribution of the augmented map to tourist map use and motivate the discussion that follows, which synthesises the findings in relation to cartographic communication principles, task demands, and implications for the future design and evaluation of augmented tourist maps.

5 DISCUSSION

Augmented maps in this thesis are presented as printed tourist maps enhanced by a mobile, screen-based overlay, combining analogue cartographic visualisation with mobile interaction. From a cartographic communication perspective, the key question is not only what a map shows, but how users notice, interpret, and act on that information in practice (Koláčný, 1969; MacEachren, 1995). However, designing and evaluating AMs in a cartographically grounded way remains challenging, particularly when established communication requirements must be maintained across both the printed and virtual layers. These requirements include symbol comprehension, visual hierarchy, and strategies for managing clutter and generalisation in dense map areas. This thesis addresses this challenge by developing and demonstrating a structured, user-oriented methodology that treats cartographic communication requirements as primary design inputs.

This chapter reflects on what the proposed methodology enables: it transforms communication problems and user priorities into clear design choices and supports an evaluation that can be meaningfully interpreted. It also discusses what the AM concept means for real map use, using effectiveness, efficiency, and satisfaction outcomes to show where augmentation is beneficial, and under which task and design conditions.

5.1 From evidence to augmented map design: formative methodological contribution

Results from the early phases demonstrate why a cartographically grounded approach is necessary before augmentation can be evaluated meaningfully. The competitive analysis shows that Croatian national park tourist maps do not provide a consistent baseline: across parks, core map elements and conventions are applied unevenly, with variable visual hierarchy and inconsistent legend explanations (see section 4.1, Table 4.1). This is important because a map is not just a collection of facts; it is a message that users must read and interpret. When the legend and the map field do not use the same visual language, users may struggle to interpret symbols quickly and confidently (Board, 1972). As a result, users are more likely to miss relevant information or assign a meaning to a symbol that the map was not intended to communicate. In this context, the existing maps should be examined to identify the specific communication weaknesses that justify their refinement and possible augmentation.

User input gathered through the questionnaire reinforced this point. Pictograms carry most of the thematic information on tourist maps (Konstantinou et al., 2023; Kostelnick et al., 2008; Medynska-Gulij, 2008), yet many symbols currently used on Croatian national park maps do not function as reliable cues for typical users. This pattern indicates a consistent communication risk, as mentioned in section 4.2. It also highlights the difference between simply noticing a pictogram and actually understanding it: users may see the symbol but still misinterpret its meaning if the design is too ambiguous or depends heavily on prior familiarity with particular cartographic conventions. Taken together, these findings show that map improvement is not purely aesthetic. Augmentation should be a purpose-driven design decision that addresses specific communication weaknesses, rather than a novelty feature introduced for its own sake. For augmented tourist maps, this implies that AR should not be used to 'rescue' weak symbols; the symbol system and legend logic must be robust first, and augmentation should reduce interpretation burden rather than add to it.

The user needs assessment clarified what users prioritise on tourist maps (see section 4.2, Table 4.5), which guided the allocation of layers: high-priority categories remained on the printed layer for quick access, while lower-priority categories were moved to the virtual layer. This reduced clustering in dense areas without making users feel that something obvious was missing. In this way, the early phases do not merely describe problems but translate them into requirements that make map augmentation meaningful.

This translation from evidence to design is most evident in how augmentation was implemented. The AM concept operationalised users' priority rankings through a layering strategy that divided tourist information between a printed layer and a virtual overlay. By moving lower-priority objects into the virtual layer, the design reduces the need for symbol grouping and heavy generalisation on the printed layer, allowing selected POIs to be shown closer to their intended locations while maintaining overall cartographic balance. This defines what augmentation is intended to improve in this thesis: clearer access to information in ways that reflect users' priorities, without overloading the printed layer (see section 3.6). To examine this concept under controlled conditions, the study compared an analogue benchmark with a proposed augmented solution. Because the two map versions used the same overall content and design logic, the usability differences are most likely linked to the augmentation and information distribution, rather than unequal map design. Some individual task targets had to differ between conditions, so the task-by-task results should be interpreted with caution. Framed in this way, augmentation is treated as a cartographic decision about information distribution, and the usability results indicate whether this distribution supports map use under the tested conditions.

The expert review demonstrates the iterative nature of the methodological workflow. Expert feedback prompted a targeted return to the user-needs evidence and subsequent prototype refinement, ensuring that the final layered concept was better aligned with cartographic purpose and interpretability. This helped to eliminate avoidable design issues and kept the summative comparison focused on the layered augmentation concept.

Cartography experts confirmed the cartographic baseline and highlighted requirements that were particularly important for the AM concept (see section 4.4, Table 4.7). First, experts emphasised that first-time users of an augmented map should immediately recognise that additional AR content is present. This led to the addition of a clear note on the printed layer of the augmented map, making it evident that further content exists. Second, they recommended moving virtual-only symbols to a fixed on-screen legend rather than including them in the printed legend. This clarified the layer logic and reduced the likelihood that users would search for virtual content in the printed legend. These points indicate that a clear distinction between the printed and virtual layers is not a minor interface detail, but a core design requirement for AM readability. Expert feedback also helped to maintain user priorities in perspective. Replacing the toilet pictogram with a viewpoint pictogram demonstrates that user evidence can inform design decisions, but should not be followed mechanically, especially when it conflicts with map purpose or interpretive clarity. Similarly, some suggestions, such as richer AR interaction, were deliberately not implemented because they would have reduced stimulus comparability and introduced confounds that the controlled evaluation design was intended to avoid. In this thesis, the aim is not to reproduce the full range of mobile mapping interactions within AR, but to apply the proposed methodology to a cartographically acceptable layering concept and to assess whether an AM designed in this way is usable in practice, and where it adds value compared with an analogue benchmark. Experts also confirmed that the overall testing protocol and task sets were realistic and appropriately challenging, and their feedback helped to remove ambiguity in the distance-comparison task wording.

5.2 Summative usability comparison: implications for augmented tourist maps

The summative comparison shows how the AM performs against an analogue benchmark. As most users are already familiar with analogue maps, the analogue condition provides a realistic reference for usable map reading in this context. With both map versions being cartographically sound, the key question is whether the augmented solution performs at least as well as the analogue map in terms of effectiveness, efficiency, and satisfaction.

5.2.1 Effectiveness

Regarding effectiveness, both conditions generally supported successful task completion, and the comparison does not indicate a consistent advantage for either map. This suggests that the augmented solution can achieve a level of correctness comparable to familiar analogue map use, without a meaningful drop in accuracy. However, the absence of a uniform effectiveness advantage does not mean that augmentation is irrelevant; rather, it suggests that accuracy in tourist map use depends on additional cognitive processes beyond visualisation alone, such as symbol interpretation, attention, and integration of spatial relations (Montello, 2002; Ratajski, 1971; Slocum et al., 2023). In this sense, augmentation may change how information is visualised, but it does not automatically guarantee better understanding of the information or the task.

At the task level, success rates were broadly comparable between the analogue and augmented conditions (see section 4.5, Figure 4.10). However, two tasks showed clear augmentation effects in opposite directions: the navigational Task 4 was completed more successfully with the analogue map, while the final distance-comparison Task 6 was completed more successfully with the augmented map (see section 4.5, Table 4.8). Overall, this pattern suggests that augmentation affected task success in a task-dependent way rather than as a consistent improvement. It is also important to note that Tasks 3 and 6 were the most direct tests of the layered AM concept, as they operationalised a “which is closer” judgement using pictograms that were intentionally represented differently between the two stimuli. In the analogue condition, the relevant POIs were presented using grouped pictograms (a generalisation strategy in dense areas), whereas the augmented stimulus showed their functional equivalents without grouping by relocating part of the content to the virtual layer. As such, Tasks 3 and 6 provide the clearest task-level evidence regarding whether the layer split helps users make proximity judgements when the printed map would otherwise rely on grouping. It should also be noted that the exact locations and target POIs differed between conditions, so some task-level differences may reflect the specific spatial layout of the chosen objects, rather than the map medium alone. Because no post-task explanations were collected, the reasons behind these task differences could not be confirmed. Still, a possible explanation is that Task 4 depends on staying oriented and continuously tracing the route; in the augmented condition, having to shift attention between the paper map and the virtual overlay may have disrupted that flow. Task 6, in contrast, is more comparison-driven, and it may have benefited from the printed layer being less visually crowded and from the overlay making the relevant POIs easier to identify, which could support more accurate judgements. Even so, the results indicate that the AM concept can perform comparably to the analogue baseline on several tasks, while also introducing task-specific advantages and risks that should be examined in future work. This makes the efficiency results particularly important for understanding where augmentation reduces effort even when correctness is similar.

5.2.2 Efficiency

The most consistent contribution of the augmented condition was improved efficiency. Participants generally completed tasks faster with the augmented map, even when only correctly completed trials were considered (see section 4.5, Figure 4.11). This suggests that augmentation's main contribution was not necessarily to increase correctness, but to reduce the effort required to reach a correct answer. A likely reason is that moving selected POIs into the virtual layer reduced symbol density on the printed layer, so users had fewer symbols to scan before finding what they needed. This, in turn, helped them confirm their answers more quickly, despite the additional attention shift involved in consulting an on-screen overlay.

The task-level pattern supports this interpretation. The largest time savings occurred in Tasks 3, 5, and 6, indicating that the augmented condition was most beneficial when tasks required search, comparison, or repeated checking of object locations (see section 4.5, Table 4.10). By contrast, Tasks 2 and 4 showed only small time differences, suggesting that augmentation had little effect on completion time for those task requirements. Taken together, the efficiency findings provide the clearest evidence that the augmented concept can reduce effort in map use, even when effectiveness remains broadly comparable to the analogue benchmark.

5.2.3 Satisfaction

The satisfaction results indicate that both map conditions were experienced as usable and acceptable (see section 4.5, Table 4.11). SUS scores were high for both maps and did not differ significantly, and post-test ratings were consistently positive. In the post-test preference item asking whether either map felt more intuitive or easier to use, many participants reported no difference, while the remaining responses were split between the analogue and augmented maps. This suggests that users were able to complete the tasks without major difficulty, and that adding a virtual layer did not reduce perceived usability. This is unsurprising in a comparison where both stimuli were iteratively refined and designed to be readable. When both maps achieve a good baseline of clarity, a global measure such as SUS may be less sensitive to differences between them, particularly when the augmentation is implemented as a simple virtual overlay rather than as a feature-rich interactive system. One additional order effect was observed: users rated the AM more positively when they experienced it second. This suggests that the augmented concept may feel more intuitive after a short familiarisation, but this interpretation should be tested more directly in future work. Overall, satisfaction indicates that the AM is perceived as usable and supports the acceptability of the augmentation, with the efficiency results showing its clearest practical advantage.

5.2.4 Individual differences and order effects

A reasonable concern in a within-subject comparison is whether the observed differences reflect the map concept itself or are largely shaped by participants' characteristics. In this sample, exploratory checks suggest that the main usability pattern is broadly stable across participant characteristics: gender and self-reported spatial ability (SBSOD) were not meaningfully associated with task success, completion time, or satisfaction in either condition. Age-related patterns were also generally weak, with one age-related difference in effectiveness in the augmented condition that should be treated as an indication for targeted follow-up rather than a firm conclusion (see section 4.5, Figure 4.12).

Map order effects help clarify whether a familiarisation can shape map experience. Task accuracy was robust to sequence for both maps, indicating that the effectiveness findings are not explained by learning or fatigue across sessions. However, participants were faster on the analogue map when it was presented second, and SUS scores were higher for the augmented map when it was experienced second. This pattern shows that brief exposure to the task format and symbol environment can reduce time costs and increase comfort – particularly for the AM concept. Given participants' generally low self-reported familiarity with AR, novelty effects may have contributed to the observed order pattern.

Taken together, these tests support the interpretation that the main pattern is primarily linked to the map condition and the augmentation concept, while presentation order can still shape efficiency and perceived usability.

5.3 Limitations and scope

The results should be interpreted within the scope of this study. This thesis does not evaluate AR as a technology, but rather a cartographically grounded AM design: whether relocating selected thematic content (in this case, POI pictograms) from the printed map into a virtual overlay can improve legibility while maintaining positive usability outcomes. The decision to augment pictograms was informed by user needs; however, the methodological point is broader in principle, and the results should not be considered generally applicable to all AR-related products.

Several aspects were intentionally excluded from the scope. The augmented layer was implemented as a marker-based, static 2D overlay, so the conclusions do not extend to more complex AR implementations that introduce different perceptual and interaction demands (e.g., 3D content, location-based augmentation, head-worn displays, or interactive map layers). Such products would require a different benchmark for fair comparison.

The main limitations are linked to the study design and test setup. Most importantly, participants did not immediately realise that the printed map contained a virtual layer, even though the printed map included a note. This suggests that the instruction and signalling could have been more explicit (e.g., a stronger visual cue such as a QR-style marker). Testing was conducted in laboratory conditions, which supports control but limits ecological validity for real tourist use in real environments, where movement, distractions, and time pressure shape behaviour. In addition, the participant group showed relatively high SBSOD scores ($M = 5.12$, $SD = 0.94$, $n = 48$), which likely reduced variability and may have masked stronger individual-difference effects. Finally, task-level interpretation is constrained by the lack of explanatory data (e.g., post-task probes), which reduces the precision with which differences between tasks can be explained.

A further limitation concerns the questionnaire measures. SUS scores should be interpreted cautiously because the questionnaire was administered in Croatian, and a formally validated

Croatian version is not available. In addition, both stimuli were refined to a high baseline of readability, which may reduce the sensitivity of a global measure such as SUS to condition differences.

A major limitation concerns how "perception of map content" was assessed. A direct assessment of perception would require a dedicated perceptual experiment (e.g., controlled visual search or symbol recognition). This was not included for two reasons. First, it would examine perception largely in isolation, outside task-based map use, and would not capture key demands of layered maps such as shifting attention between the printed map and the screen. Second, it would substantially extend the study session and increase participant workload, undermining the flow and feasibility of the benchmark comparison. Instead, this thesis treats "perception of map content" as perception during use—that is, users' perceived ability to access and work with thematic information while completing map tasks. In line with the ISO emphasis on evaluating interaction outcomes in a defined context of use (ISO 9241-210:2019), perception was operationalised through user-reported judgements collected during task work (SUS and post-test ratings of ease and acceptability). This approach supports ecological validity and a fair benchmark comparison. At the same time, it means that fine-grained perceptual mechanisms were not isolated and remain a topic for future targeted perceptual testing.

Future work should test the same concept in more field-like settings, add brief post-task questions to support task-level interpretation, and include direct workload and acceptance measures (e.g., attention switching and perceived effort-to-benefit when combining paper and screen), alongside ISO usability outcomes. The task-level effectiveness differences observed here should also be replicated in a larger sample with a wider age range and greater diversity in SBSOD scores. Future studies may also account for participants' prior familiarity with AR when interpreting learnability or order effects. Purposeful interactivity should be explored to better reflect mobile user expectations and to test whether it improves perceived benefit without increasing switching costs.

5.4 Assessment of hypotheses

With the study scope and limitations established, the thesis hypotheses can now be evaluated against the evidence produced by the proposed methodology and the benchmarked usability comparison.

H1. Augmented tourist maps improve the exact position of objects shown on the map using pictograms without disturbing the cartographic balance.

This hypothesis is supported within the scope of the tested concept. In this thesis, “exact position” refers to improved positional fidelity of pictograms on the printed layer: reduced need for displacement or grouping in dense areas. The layering strategy reduced symbol density on the printed layer by relocating lower-priority content to the virtual layer, which allowed selected POIs to be placed closer to their intended locations within the constraints of the map scale and design rules. The expert checkpoint indicates that this was achieved without compromising overall legibility and balance, and the usability results are consistent with this outcome: effectiveness was largely comparable across conditions, while efficiency improved in the augmented condition, with high overall satisfaction.

H2. Virtual content on augmented maps improves the user's perception of the map content.

This hypothesis is partially supported when “perception of the map content” is interpreted as it was operationalised in this thesis – through user-reported judgements of how easy and acceptable it felt to work with the map’s thematic information during task completion. On this basis, the augmented map was perceived as at least as usable as the analogue map: SUS scores were high in both conditions and post-test experience ratings were consistently positive. However, the preference item asking whether either map felt more intuitive or easier to use did not show a consistent advantage for the augmented condition, with many participants reporting no difference and the remainder split between the two maps. This indicates that any improvement in users’ perceived interaction with map content is modest rather than universal and may depend on task demands or brief familiarisation, as also indicated by more positive ratings when the augmented map was experienced second.

Taken together, the hypothesis outcomes show that the developed augmented concept is feasible and acceptable, but its benefits are expressed most clearly through reduced effort rather than uniform gains in correctness. The following guidelines translate these findings into practical design requirements for layered AMs.

5.5 Design implications: guidelines for augmented tourist maps

Based on the analyses conducted, guidelines can be established for developing layered augmented maps. The results indicate that AMs are most effective when designed as a single cartographic product, with the virtual layer serving a clear purpose: relocating selected content that would otherwise overload the printed layer, while ensuring map reading remains smooth and predictable. The following guidelines translate these findings into practical design requirements:

1. Start with a print-layer problem, not an AR feature.

Augmentation should address a specific cartographic issue on the printed map (e.g., crowding, competing symbols, excessive thematic detail for the chosen scale). If augmentation is added simply because AR is available, it risks increasing effort without improving map usability.

2. Ensure the printed map remains usable on its own.

As users may not activate the overlay immediately, the printed layer should still support basic orientation and understanding. The overlay can extend the map, but it should not be necessary for the map to be comprehensible.

3. Make the presence of the overlay obvious on the paper map.

In this study, some participants did not immediately realise that a virtual layer existed. A clear and visible cue on the printed map (e.g., a QR-style marker) helps prevent the concept from failing at the discovery stage.

4. Maintain a consistent visual identity across paper and overlay.

Layering is only effective if recognition transfers instantly. The paper map and virtual overlay should therefore follow the same symbol logic and visual style. If the overlay appears as a separate system, it introduces additional interpretation work instead of reducing it.

5. Use a layer-appropriate legend strategy.

Users should not have to guess which symbols belong to which layer. A clear legend split (i.e., separate legend elements) helps prevent confusion and supports faster symbol interpretation and search.

6. Control overlay density and apply hierarchy in the virtual layer.

Layering can easily transfer clutter from paper to screen, so the virtual layer should also follow cartographic hierarchy and remain readable. Augment only content that serves user needs, rather than adding information simply because it can be displayed.

7. Prioritise stable alignment and clear anchoring.

For successful map reading, the overlay must function as a precise cartographic layer. Even minor registration issues or “floating” behaviour can reduce trust and slow task execution. Stability and clear anchoring should be treated as quality requirements.

8. Design to minimise attention switching between paper and screen.

Layered AMs create split attention between paper and screen. When users must constantly switch between layers, efficiency benefits can be lost and perceived effort can increase. Design should therefore reduce unnecessary switching by keeping the virtual layer clear, stable, and consistent with the printed layer.

9. Clearly communicate the interaction offered by the overlay.

Users often associate AR with interactivity. If the overlay is intended as a static visibility layer, this should be communicated through both design and instructions. If interaction is introduced, it should serve a clear cartographic purpose (e.g., reducing density through filtering), as interaction shifts the augmented map towards a different type of product and changes user expectations.

These guidelines describe the conditions under which layered AMs are most likely to support map use without increasing interpretation burden. In tourist settings, this type of layering may also provide a practical channel for additional or changeable visitor information without overloading the printed map, although these operational benefits were not directly evaluated in this thesis. Beyond the guidelines themselves, the thesis contributes the methodology that produced them: a user-oriented workflow that links evidence to cartographic decisions and tests the concept under controlled conditions.

5.6 Methodological contribution

The methodological contribution of this thesis lies in the user-oriented workflow used to justify, develop, refine, and evaluate a cartographically grounded AM concept. The Croatian national park case served as a concrete demonstration of how the methodology can be applied in practice, and the process was iteratively refined and validated through expert review. In this sense, the contribution is not a single prototype outcome, but a structured and traceable approach to moving from user-oriented evidence to a usable AM design and an interpretable usability evaluation. This contribution can be summarised through six practical elements of the methodology:

1. A clear five-phase structure that follows UCD logic.

The work progresses through analysis, needs assessment, design/prototyping, expert review, and user testing, with iteration between steps as needed. This is important because AMs lack design conventions, so iterative refinement before final testing is essential.

2. A direct link between user input and design decisions.

User priorities are not treated as background information; they form the evidence base for deciding what the map should emphasise, what can be reduced on paper, and what can be shifted to the virtual layer. A key benefit is that it keeps the concept needs-led rather than technology-led.

3. An expert checkpoint that improves the stimuli before measuring usability.

Expert review is used as a formative step to identify and resolve issues early, with changes documented through a refinement log (for example, separating legend logic). This helps ensure that avoidable design flaws are addressed early, reducing the risk of distorted usability outcomes.

4. A matched-stimuli approach that keeps the comparison fair.

The analogue and AM versions follow the same overall content and symbol logic, differing only in where the information is placed (printed layer versus virtual layer). From an evaluation standpoint, this supports an interpretable comparison, so differences can be attributed to layering rather than unrelated design variation.

5. A controlled usability study design with clear outcome measures.

The user-based usability test uses a within-subject, counterbalanced procedure and measures effectiveness, efficiency, and satisfaction consistently. This reduces the influence of presentation order and individual variability, and keeps the evaluation aligned with established usability logic.

6. A transparent operationalisation that others can replicate or extend.

The AM was deliberately implemented as a marker-based, static 2D overlay with a limited number of virtual objects, and the thesis documents the key implementation checks (e.g., legibility, consistency, marker stability, alignment). In practice, this clarifies what was tested and provides a baseline that future work can reproduce and extend. Crucially, the thesis documents the decision rules for layer allocation and stimuli matching, so others can reproduce the same logic rather than only the final artefacts.

Taken together, the methodology offers a repeatable way to design and evaluate layered, cartographically grounded AMs: it links user-oriented evidence to cartographic decisions, improves the design through expert refinement, and then tests the concept under controlled conditions. Although this thesis applies augmentation through a printed–virtual layer split of POI pictograms, the same methodology can be used for other augmentation targets (e.g., seasonal features, road classifications, temporary changes, or additional explanatory text), as long as the choices remain needs-led and the evaluation logic remains comparable.

5.7 Chapter summary

This chapter interprets the thesis findings by treating augmentation as a cartographic decision regarding the distribution of information between printed and virtual layers. It demonstrates how the proposed user-oriented methodology translated observed communication weaknesses and user priorities into a layered design, which was refined through expert review and then evaluated against an analogue benchmark. Overall, the usability comparison suggests that the layered AM concept can achieve satisfaction and effectiveness comparable to analogue map use, with its most evident benefit being improved efficiency. Based on these outcomes, the chapter proposes practical design guidelines for AMs and summarises the methodological workflow as a transferable contribution for future cartographically grounded AM design and evaluation.

6 CONCLUSION

Tourist maps help visitors organise activities and navigate unfamiliar places, which is especially important in nature-based destinations. Meanwhile, the tourism industry is increasingly investing in mobile and AR technologies to attract visitors and enhance on-site experiences. From a cartographic perspective, however, adding a virtual layer changes how people perceive and interpret map information, meaning that augmentation can either support or hinder map reading depending on its design. This issue is addressed by evaluating when augmentation is justified and whether an augmented map can support map use without undermining readability. To do this, a user-oriented methodology was developed and applied; it translates communication weaknesses and user priorities into design decisions and assesses usability against an analogue benchmark.

The methodology followed an ISO-aligned user-oriented workflow that moves from evidence to design and then to evaluation. A competitive analysis of eight Croatian national park tourist maps identified cartographic communication weaknesses, including inconsistent symbol conventions and uneven visual hierarchy. A user needs assessment with 132 participants then established content priorities: the highest composite weighted scores were for tourism activities (823), transport (555), and food and beverage (519), and these categories were kept on the printed base map for immediate access. Lower-priority or less central categories, such as public services (231) and shopping (117), were allocated to the virtual overlay to reduce visual competition on the printed layer. This was translated into a layered augmented map concept through design and prototyping. Eight cartographers reviewed the prototype and highlighted small but important refinements: they recommended clearer signalling that AR content exists and moving virtual-only symbols to a fixed on-screen legend. Finally, a benchmarked usability comparison against an analogue map (with 48 participants) showed high effectiveness of the augmented map (81% correct answers on the analogue map vs 84% on the augmented map), while its clearest benefit emerged in efficiency: average completion time decreased from 10.56 seconds to 7.61 seconds per task, despite the added step of consulting a screen, with 73% of participants faster in the augmented condition. Perceived usability was high for both maps (SUS scores 87.29 for the analogue map vs 89.32 for the augmented map), indicating that the augmented map can match analogue usability while reducing effort.

Overall, the benchmarked comparison shows that the proposed AM concept can preserve task correctness while reducing effort in map use, with the clearest value emerging in efficiency rather than uniform gains in effectiveness. Within the tested scope, H1 is supported and H2 is partially supported: augmentation maintained overall usability, while perceived advantages of the virtual layer were modest and varied across tasks and familiarisation. At the same time, the results point to a key condition for such augmented maps: making the switch between paper and screen as easy as possible, because tasks that require frequent back-and-forth can reduce the benefit of augmentation. Although evaluated through a national park tourist map case study, this layered augmented map concept is intended as a general cartographic augmentation strategy that can be applied to other printed map types with dense thematic content, provided that attention switching between layers is carefully managed.

The contributions are twofold. First, a repeatable, ISO-aligned user-oriented methodology sets out a clear path from evidence on cartographic communication and user priorities to concrete design decisions, expert refinement, and a benchmarked usability comparison. Second, a practical insight into augmented tourist maps is provided: distributing information between a printed and a virtual layer can preserve usability while improving efficiency, but the concept adds value only when attention switching between layers is carefully managed.

Future work should test the AM concept in more realistic tourist-use settings and include measures that capture the effort of shifting attention between the printed and virtual layers, as well as user acceptance during task performance. Replication with a larger and more diverse sample, especially a wider age range and greater variation in SBSOD scores, would strengthen generalisability and help confirm whether the observed age-related differences are reliable. Purposeful interactivity could also be explored to reflect mobile user expectations without increasing switching costs.

When designed as a cartographic information-distribution strategy, the augmented map can match analogue map usability while reducing effort.

REFERENCES

Adithya, C., Kowsik, K., Namrata, D., Nageli, V.S., Shrivastava, S. and Rakshit, S. (2010). Augmented reality approach for paper map visualization. *2010 International Conference on Communication and Computational Intelligence (INCOCCI)*, 352-356.

Airikka, M. and Masoodian, M. (2019). A survey of the visual design of cartographic and other elements of illustrated tourist maps. In *2019 23rd International Conference on Information Visualization – Part II*, 7–13. https://doi.org/10.1109/IV-2.2019.00011.

Alroobaea, R. and Mayhew, P. J. (2014). How many participants are really enough for usability studies? In *2014 Science and Information Conference*, 48–56. https://doi.org/10.1109/SAI.2014.6918171.

Amorim, F. R. and Schmidt, M. A. R. (2021). Classification of Dynamic Cartographic Symbols applied to Augmented Reality (AR) Systems. In *Proceedings of the ICA, 4,* 8. https://doi.org/10.5194/ica-proc-4-8-2021.

Anastopoulou, N., Kokla, M., Tomai, E., Cheliotis, K., Liarokapis, F., Pastra, K. and Kavouras, M. (2023). Cartographic perspectives on spatial and thematic levels of detail in augmented reality: a review of existing approaches. *International Journal of Cartography, 9*(2), 373–391. https://doi.org/10.1080/23729333.2023.2228592.

Apple (2024). Augmented reality. Apple Developer Documentation. Available at: https://developer.apple.com/design/human-interface-guidelines/augmented-reality (Accessed: 10 January 2026).

Asai, K., Kondo, T., Kobayashi, H. and Mizuki, A. (2008). A Geographic Surface Browsing Tool Using Map-Based Augmented Reality. In *2008 International Conference Visualisation*, 93–98. https://doi.org/10.1109/VIS.2008.25.

Azuma, R. T. (1997). A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments, 6*(4), 355–385. https://doi.org/10.1162/pres.1997.6.4.355.

Bartling, M., Resch, B., Reichenbacher, T., Havas, C. R., Robinson, A. C., Fabrikant, S. I. and Blaschke, T. (2022). Adapting mobile map application designs to map use context: a review and call for action on potential future research themes. *Cartography and Geographic Information Science, 49*(3), 237–251. https://doi.org/10.1080/15230406.2021.2015720.

Bednarczyk, M. (2017). Application possibilities of augmented reality in analog maps. In *Geographic Information Systems Conference and Exhibition "GIS ODYSSEY 2017"*.

Available at: https://www.researchgate.net/publication/329118357 (Accessed: 10 January 2026).

Bellmund, J. L. S., Gärdenfors, P., Moser, E. I. and Doeller, C. F. (2018). Navigating cognition: Spatial codes for human thinking. *Science*, *362*(6415). https://doi.org/10.1126/SCIENCE.AAT6766.

Bergmann Martins, V., Rosa Amorim, F., Augusto Reolon Schmidt, M., and Stamato Delazari, L. (2023). Study about the appropriate number of participants in map user studies. *International Journal of Cartography*, *9*(2), 196–209. https://doi.org/10.1080/23729333.2022.2163142.

Bertin, J. (1967). *Semiology of graphics*. University of Winsconsin Press.

Besharat, J., Komninos, A., Papadimitriou, G., Lagiou, E. and Garofalakis, J. (2016). Augmented paper maps: Design of POI markers and effects on group navigation. J*ournal of Ambient Intelligence and Smart Environments, 8*(5), 515–530. https://doi.org/10.3233/AIS-160395.

Bevan, N. and Macleod, M. (1994). Usability measurement in context. *Behaviour & Information Technology*, *13*(1–2), 132–145. https://doi.org/10.1080/01449299408914592.

Bevan, N. (1995). Usability is Quality of Use. *Advances in Human Factors/Ergonomics*, *20*, 349–354. https://doi.org/10.1016/S0921-2647(06)80241-8.

Bevan, N., Carter, J., Earthy, J., Geis, T. and Harker, S. (2016). New ISO standards for usability, usability reports and usability measures. In Kurosu, M. (ed), *Human-computer interaction. Theory, design, development and practice* (Lecture Notes in Computer Science), *9731*, 268–278. Springer. https://doi.org/10.1007/978-3-319-39510-4_25.

Board, C. (1972). Cartographic communication. *Cartographica*, *18*(2), 42-78.

Board, C. (1978). Map reading tasks appropriate in experimental studies in cartographic communication. *Cartographica, 15*(1), 1–12. https://doi.org/10.3138/ag15-v252-3726-w346.

Bobrich, J. and Otto, S. (2002). Augmented maps. *International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences*, *4*(34), 502–505. Available at: https://www.isprs.org/proceedings/XXXIV/Part4/pdfpapers/451.pdf (Accessed: 10 January 2026).

Bosworth, G. and Curry, N. (2020). National Parks. In *International Encyclopedia of Human Geography*, 229–237. Elsevier. https://doi.org/10.1016/B978-0-08-102295-5.10013-7.

Bowman, D. A., Gabbard, J. L. and Hix, D. (2002). A Survey of Usability Evaluation in Virtual Environments: Classification and Comparison of Methods. *Presence: Teleoperators & Virtual Environments, 11*(4), 404–424. https://doi.org/10.1162/105474602760204309.

Brooke, J. (1996). SUS - A quick and dirty usability scale. Available at: https://digital.ahrq.gov/sites/default/files/docs/survey/systemusabilityscale%2528sus%2529_comp%255B1%255D.pdf (Accessed: 10 January 2026).

Brügger, A., Richter, K. F. and Fabrikant, S. I. (2019). How does navigation system behavior influence human behavior? *Cognitive Research: Principles and Implications. 4*(1), 1–22. https://doi.org/10.1186/S41235-019-0156-5.

Buchner, J., Buntins, K. and Kerres, M. (2021). A systematic map of research characteristics in studies on augmented reality and cognitive load. *Computers and Education Open, 2,* 100036. https://doi.org/10.1016/j.caeo.2021.100036.

Budiu, R. and Moran, K. (2021). How many participants for quantitative usability studies: A summary of sample-size recommendations. Nielsen Norman Group. Available at: https://www.nngroup.com/articles/summary-quant-sample-sizes/ (Accessed: 10 January 2026).

Burnett, G. E. and Lee, K. (2005). The Effect of Vehicle Navigation Systems on the Formation of Cognitive Maps. In *Traffic and transport psychology: Theory and application. Proceedings of the ICTTP 2004*. 407–418. https://doi.org/10.1016/B978-008044379-9/50188-6.

Buttenfield, B. (1999). Usability evaluation of digital libraries. *Science and Technology Libraries, 17*(3-4), 39–59. https://doi.org/10.1300/J122V17N03_04.

Cabeleira, M. and Vaz de Carvalho, C. (2025). Using Augmented Reality to Improve Touristic Efficacy. *Computers, 14*(2), 75. https://doi.org/10.3390/computers14020075.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E. and Ivkovic, M. (2011). Augmented reality technologies, systems and applications. *Multimedia Tools and Applications, 51*, 341–377. https://doi.org/10.1007/s11042-010-0660-6.

Carrera, C. C., Perez, J. L. S. and Cantero, J. de la T. (2017). Teaching with AR as a tool for relief visualization: usability and motivation study. *International Research in Geographical and Environmental Education, 27*(1), 69–84. https://doi.org/10.1080/10382046.2017.1285135.

Chatain, J., Laval, D., Demangeat, M., Hachet, M. and Brock, A. M. (2015). Exploring input modalities for interacting with augmented paper maps. In *Proceedings of the 27th*

Conference on l'Interaction Homme-Machine (IHM '15). 1–6. https://doi.org/10.1145/2820619.2825002.

Cheliotis, K., Liarokapis, F., Kokla, M., Tomai, E., Pastra, K., Darra, A., Bezerianou, M. and Kavouras, M. (2021). A Classification of Augmented Reality Approaches for Spatial Data Visualization. In *2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, 367–372. https://doi.org/10.1109/ISMAR-ADJUNCT54149.2021.00084.

Cheliotis, K., Liarokapis, F., Kokla, M., Tomai, E., Pastra, K., Anastopoulou, N., Bezerianou, M., Darra, A. and Kavouras, M. (2023). A systematic review of application development in augmented reality navigation research. *Cartography and Geographic Information Science, 50*(3), 249–271. https://doi.org/10.1080/15230406.2023.2194032.

Cheng, B., Wunderlich, A., Gramann, K., Lin, E., & Fabrikant, S. I. (2022). The effect of landmark visualization in mobile maps on brain activity during navigation: A virtual reality study. *Frontiers in Virtual Reality*, *3*, 981625. https://doi.org/10.3389/frvir.2022.981625.

Cheng, Y., Zhu, G., Yang, C., Miao, G. and Ge, W. (2022). Characteristics of augmented map research from a cartographic perspective. *Cartography and Geographic Information Science, 49*(5), 426–442. https://doi.org/10.1080/15230406.2022.2059571.

Choong, Y.Y., Goad, K. and Mangold, K. C. (2022). Augmented reality (AR) usability evaluation framework: The Case of Public Safety Communications Research. Available at: https://doi.org/10.6028/NIST.IR.8422 (Accessed: 10 January 2026).

Cibilić, I., Poslončec-Petrić, V. and Matijević, M. (2024). Geovisualization of borongaj campus in mobile augmented reality. In *Proceedings of 24th International Multidisciplinary Scientific GeoConference SGEM 2024*, *24*, 291–298. https://doi.org/10.5593/sgem2024v/6.2/s26.36.

Cibilić, I., Poslončec-Petrić, V. and Tominić, K. (2021). Implementing Augmented reality in Tourism. In *Proceedings of the ICA, 4,* 1–5. https://doi.org/10.5194/ica-proc-4-21-2021.

Cibilić, I. and Poslončec-Petrić, V. (2025). Evaluating Cartographic Communication in Croatian National Parks: User Perceptions of Pictograms. *ISPRS International Journal of Geo-Information, 14*(2), 41. https://doi.org/10.3390/ijgi14020041.

Crampton, J. W. (2001). Maps as social constructions: power, communication and visualization. *Progress in Human Geography, 25*(2), 235–252. https://doi.org/10.1191/030913201678580494.

Croatian Ministry of Economy and Sustainable Development. (n.d.). Protected Areas. Available at: https://mingo.gov.hr/o-ministarstvu-1065/djelokrug-4925/zastita-prirode/zasticena-podrucja/1188 (Accessed: 10 January 2026).

Danado, J., Dias, E., Romão, T., Correia, N., Trabuco, A., Santos, C., Serpa, J., Costa, M. and Câmara, A. (2005). Mobile environmental visualization. *he Cartographic Journal*, *42*(1), 61–68. https://doi.org/10.1179/000870405X57293.

de Almeida Pereira, G. H., Stock, K., Stamato Delazari, L. and Centeno, J. A. S. (2017). Augmented Reality and Maps: New Possibilities for Engaging with Geographic Data. *The Cartographic Journal*, *54*(4), 313–321. https://doi.org/10.1080/00087041.2017.1411417.

Demonja, D., Tišma, S., Mijatov Ladičorbić, M., Dragin, A. and Stojanović, V. (2024). The contribution of environmental interpretation in nature protection. *Šumarski List*, *148*(9–10), 477–487. https://doi.org/10.31298/sl.148.9-10.5.

Dent, B. D., Torguson, J. and Hodler, T. W. (2009). *Cartography: thematic map design* (6th ed.). McGraw-Hill Higher Education.

Derby, J. L. and Chaparro, B. S. (2021). The Challenges of Evaluating the Usability of Augmented Reality (AR). In *Proceedings of the Human Factors and Ergonomics Society, 65*(1), 994–998. https://doi.org/10.1177/1071181321651315.

Dibiase, D. (1990). Visualization in the Earth Sciences. *Earth and Mineral Sciences, Bulletin of the College of Earth and Mineral Sciences, Penn State University, 59*(2), 13–18. Available at: https://www.researchgate.net/publication/239055586 (Accessed: 10 January 2026).

Dickmann, F., Keil, J., Dickmann, P. L. and Edler, D. (2021). The Impact of Augmented Reality Techniques on Cartographic Visualization. *KN - Journal of Cartography and Geographic Information, 71*(4), 285–295. https://doi.org/10.1007/s42489-021-00091-2.

Dong, W. and Liao, H. (2016). Eye tracking to explore the impacts of photorealistic 3d representations in pedstrian navigation performance. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLI-B2, 641–645. https://doi.org/10.5194/isprs-archives-XLI-B2-641-2016.

Dong, W., Wu, Y., Qin, T., Bian, X., Zhao, Y., He, Y., Xu, Y. and Yu, C. (2021). What is the difference between augmented reality and 2D navigation electronic maps in pedestrian wayfinding? *Cartography and Geographic Information Science, 48*(3), 225–240. https://doi.org/10.1080/15230406.2021.1871646.

Dong, W., Qin, T., Yang, T., Liao, H., Liu, B., Meng, L. and Liu, Y. (2022). Wayfinding Behavior and Spatial Knowledge Acquisition: Are They the Same in Virtual Reality and in Real-World Environments? *Annals of the American Association of Geographers, 112*(1), 226–246. https://doi.org/10.1080/24694452.2021.1894088.

Dowse, R. and Ehlers, M. S. (2010). The influence of education on the interpretation of pharmaceutical pictograms for communicating medicine instructions. *International Journal of Pharmacy Practice, 11*(1), 11–18. https://doi.org/10.1211/002235702810.

Dünser, A., Grasset, R. and Billinghurst, M. (2008). A survey of evaluation techniques used in augmented studies. In *International Conference on Computer Graphics and Interactive Techniques*. https://doi.org/10.1145/1508044.1508049.

Dünser, A., Billinghurst, M., Wen, J., Lehtinen, V. and Nurminen, A. (2012). Exploring the use of handheld AR for outdoor navigation. *Computers & Graphics, 36*(8), 1084–1095. https://doi.org/10.1016/J.CAG.2012.10.001.

Dünser, A., Grasset, R., Seichter, H. and Billinghurst, M. (2007). Applying HCI principles to AR systems design. In *Mixed Reality User Interfaces: Specification, Authoring, Adaptation (MRUI'07) Workshop Proceedings*, 37-42. Available at: https://ir.canterbury.ac.nz/server/api/core/bitstreams/b3a2f13e-0813-4f70-bf27-56474f96fce1/content (Accessed: 10 January 2026).

Eboy, O. V. (2017). Tourism Mapping: An Overview of Cartography and the Use of GIS. *BIMP-EAGA Journal for Sustainable Tourism Development, 6*(1), 61–67. Available at: https://www.researchgate.net/publication/334169807_TOURISM_MAPPING_AN_OVERVIEW_OF_CARTOGRAPHY_AND_THE_USE_OF_GIS (Accessed: 10 January 2026).

Eckert, M. (1925). *Die Kartenwissenschaft* (Vol. 2). Walter de Gruyter.

El Choubassi, M., Nestares, O., Wu, Y., Kozintsev, I. and Haussecker, H. (2010). An Augmented Reality Tourist Guide on Your Mobile Devices. In: Boll, S., Tian, Q., Zhang, L., Zhang, Z., Chen, YP.P. (eds) *Advances in Multimedia Modeling. MMM 2010* (Lecture Notes in Computer Science), *5916*. Springer. https://doi.org/10.1007/978-3-642-11301-7_58

Endsley, T. C., Sprehn, K. A., Brill, R. M., Ryan, K. J., Vincent, E. C. and Martin, J. M. (2017). Augmented reality design heuristics: Designing for dynamic interactions. In *Proceedings of the Human Factors and Ergonomics Society*, *61*(1), 2100–2104. https://doi.org/10.1177/1541931213602007.

Esri Mapping Center. (2007). Map Evaluation Guidelines. Available at: https://content.esri.com/mappingcenter2007/arcgisresources/more/mapevaluationguidelines.pdf (Accessed: 10 January 2026).

Frangeš, S. (2012). Comparison of two maps of Split-Dalmatia County, Tourist map – Central Dalmatia – Split-Dalmatia County and Regional map of Central Dalmatia, Split and its surroundings – school map – Split-Dalmatia County. *Kartografija i Geoinformacije, 11*(18), 140–147. Available at: https://hrcak.srce.hr/index.php/97973 (Accessed: 10 January 2026).

Frangeš, S. (2013). Analysis and Comparison of Three Tourist-Hiking Maps - Island of Vis, Nature Park Biokovo and Orjen-Snježnica. *Kartografija i Geoinformacije,* 1*2*(20), 104–113. Available at: https://hrcak.srce.hr/133748 (Accessed: 10 January 2026).

Frangeš, S., Šantek, D. and Fudurić, D. (2019). New Model and Guidelines for the Evaluation of Different Cartographic Products. *Tehnički Vjesnik, 26*(5), 1205–1210. https://doi.org/10.17559/TV-20170314091115.

Freitag, U. (1971). Semiotik und kartographie: Über die Anwendung kybernetischer Disziplinen in der theoretischen kartographie. *Kartographische Nachrichten*, 2*1,* 171–182.

Fuhrmann, S, Ahonen-Rainio, P., Edsall, R. M., Fabrikant, S. I., Koua, E. L., Tobon, C., Ware, C. and Wilson, S. (2005). Making useful and useable geovisualization: design and evaluation issues. In J. Dykes, A. M. MacEachren & M. J. Kraak (Eds.), *Exploring geovisualization*, 553–566. Elsevier. https://doi.org/10.1016/B978-008044531-1/50446-2.

Fuhrmann, S. and Pike, W. (2005). User-centered Design of Collaborative Geovisualization Tools. In J. Dykes, A. M. MacEachren & M. J. Kraak (Eds.), *Exploring Geovisualization*, 591–609. Elsevier. https://doi.org/10.1016/B978-008044531-1/50449-8.

Gabbard, J.L., Hix, D. and Swan, J. E. (1999). User-centered design and evaluation of virtual environments. In *IEEE Computer Graphics and Applications*, *19*(6), 51–59. https://doi.org/10.1109/38.799740.

Gabbard, Joseph L. and Swan, J. E. (2008). Usability engineering for augmented reality: Employing user-based studies to inform design. In *IEEE Transactions on Visualization and Computer Graphics, 14*(3), 513–525. https://doi.org/10.1109/TVCG.2008.24.

Gardony, A. L., Brunyé, T. T. and Taylor, H. A. (2015). Navigational Aids and Spatial Memory Impairment: The Role of Divided Attention. S*patial Cognition and Computation, 15*(4), 246–284. https://doi.org/10.1080/13875868.2015.1059432.

Garrett, J. J. (2002). *The Elements of User Experience: User-Centered Design for the Web*. (Vol. 10). American Institute of Graphic Arts.

Ghaderi, Z., Hatamifar, P. and Ghahramani, L. (2019). How smartphones enhance local tourism experiences? *Asia Pacific Journal of Tourism Research*, *24*(8), 778–788. https://doi.org/10.1080/10941665.2019.1630456.

Ghayas, S., Sulaiman, S., Khan, M. and Jaafar, J. (2013). The Effects of Icon Characteristics on Users' Perception. In Zaman, H. B., Robinson, P., Olivier, P., Shih, T. K. and Velastin, S. (eds), *Advances in visual informatics. IVIC 2013* (Lecture Notes in Computer Science), *8237*, 652–663. Springer. https://doi.org/10.1007/978-3-319-02958-0_59.

Goldiez, B. F., Ahmad, A. M. and Hancock, P. A. (2007). Effects of augmented reality display settings on human wayfinding performance. In *IEEE Transactions on Systems, Man and Cybernetics Part C (Applications and Reviews)*, *37*(5), 839–845. https://doi.org/10.1109/TSMCC.2007.900665.

Google. (2024). Augmented reality design guidelines. ARCore, Google for Developers. Available at: https://developers.google.com/ar/design (Accessed: 10 January 2026).

Gould, J. D. and Lewis, C. (1985). Designing for usability: Key principles and what designers think. *Communications of the ACM*, *28*(3), 300–311. https://doi.org/10.1145/3166.3170.

Grant, L. and Keller, C. (1999). Content and Design of Canadian Provincial Travel Maps. C*artographica*, *36*(1), 51–62. https://doi.org/10.3138/2T07-6264-1394-1820.

Graser, S., Kirschenlohr, F. and Böhm, S. (2024). User Experience Evaluation of Augmented Reality: A Systematic Literature Review. In *Proceedings of the 17th International Conference on Advances in Human-Oriented and Personalized Mechanisms, Technologies, and Services CENTRIC 2024*, 23–40. https://doi.org/10.48550/arXiv.2411.12777.

Griffin, A. L., White, T., Fish, C., Tomio, B., Huang, H., Sluter, C. R., Bravo, J. V. M., Fabrikant, S. I., Bleisch, S., Yamada, M. and Picanço, P. (2017). Designing across map use contexts: a research agenda. *International Journal of Cartography*, *3*(sup1), 90–114. https://doi.org/10.1080/23729333.2017.1315988.

Griffin, A. L., Reichenbacher, T., Liao, H., Wang, W. and Cao, Y. (2024). Cognitive issues of mobile map design and use. *Journal of Location Based Services*, *18*(4), 350–380. https://doi.org/10.1080/17489725.2024.2371288.

Griffith, A. and Headley, J. D. (1997). Using a weighted score model as an aid to selecting procurement methods for small building works. *Construction Management and Economics*, *15*(4), 341–348. https://doi.org/10.1080/014461997372890.

Grubert, J., Pahud, M., Grasset, R., Schmalstieg, D. and Seichter, H. (2014). The utility of Magic Lens interfaces on handheld devices for touristic map navigation. *Pervasive and Mobile Computing*, *18,* 88–103. https://doi.org/10.1016/J.PMCJ.2014.08.005.

Guelke, L. (1976). Cartographic communication and geographic understanding. *Cartographica*, *13*(2), 107–122. https://doi.org/10.3138/m443-1606-5701-8648.

Hake, G. (1973). Kartographie und Kommunikation. *Kartographische Nachrichten*, *23*, 137–148.

Haklay, M. and Tobón, C. (2003). Usability evaluation and PPGIS: Towards a user-centred design approach. *International Journal of Geographical Information Science*, *17*(6), 577–592. https://doi.org/10.1080/1365881031000114107.

Haklay, M. and Zafiri, A. (2008). Usability engineering for GIS: Learning from a screenshot. *The Cartographic Journal*, *45*(2), 87–97. https://doi.org/10.1179/174327708X305085.

Haklay, M. M. and Nivala, A. M. (2010). User-Centred Design. In M. M. Haklay (Ed.), *Interacting with Geospatial Technologies*, 89–106. Wiley Blackwell. https://doi.org/10.1002/9780470689813.CH5.

Halik, Ł. (2012). The analysis of visual variables for use in the cartographic design of point symbols for mobile Augmented Reality applications. *Geodesy and Cartography*, *61*(1), 19–30. https://doi.org/10.2478/v10277-012-0019-4.

Halik, Ł. and Medyńska-Gulij, B. (2017). The Differentiation of Point Symbols using Selected Visual Variables in the Mobile Augmented Reality System. *The Cartographic Journal*, *54*(2), 147–156. https://doi.org/10.1080/00087041.2016.1253144.

Hammady, R., Ma, M. and Powell, A. (2018). User Experience of Markerless Augmented Reality Applications in Cultural Heritage Museums: 'MuseumEye' as a Case Study. In: De Paolis, L., Bourdot, P. (eds) *Augmented Reality, Virtual Reality, and Computer Graphics. AVR 2018*. (Lecture Notes in Computer Science), *10851*. Springer, Cham. https://doi.org/10.1007/978-3-319-95282-6_26.

Han, DI., Jung, T. and Gibson, A. (2013). Dublin AR: Implementing Augmented Reality in Tourism. In: Xiang, Z., Tussyadiah, I. (eds) *Information and Communication Technologies in Tourism 2014*. Springer, Cham. https://doi.org/10.1007/978-3-319-03973-2_37.

Han, D.I., tom Dieck, M. C. and Jung, T. (2018). User experience model for augmented reality applications in urban heritage tourism. *Journal of Heritage Tourism*, *13*(1), 46–61. https://doi.org/10.1080/1743873X.2016.1251931.

Harley J.B. (2009). Maps, knowledge, and power. In G. Henderson & M. Waterstone (Eds.), *Geographic thought: a praxis perspective*, 129–148. Routledge.

Harrower, M., Mac Eachren, A. and Griffin, A. L. (2000). Developing a geographic visualization tool to support Earth Science learning. *Cartography and Geographic Information Science*, *27*(4), 279–293. https://doi.org/10.1559/152304000783547759.

Hedley, N. (2017). Augmented Reality. In: *International Encyclopedia of Geography*, 1–13. https://doi.org/10.1002/9781118786352.wbieg0961.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K. and Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence*, *30*(5), 425–447. https://doi.org/10.1016/S0160-2896(02)00116-2.

Hejtmánek, L., Oravcová, I., Motýl, J., Horáček, J. and Fajnerová, I. (2018). Spatial knowledge impairment after GPS guided navigation: Eye-tracking study in a virtual town. *International Journal of Human-Computer Studies*, *116*, 15–24. https://doi.org/10.1016/j.ijhcs.2018.04.006.

Herman, L., Juřík, V., Stachoň, Z., Vrbík, D., Russnák, J. and Řezník, T. (2018). Evaluation of user performance in interactive and static 3D maps. *ISPRS International Journal of Geo-Information*, *7*(11), 415. https://doi.org/10.3390/ijgi7110415.

Hix, D., Swan, J. E., Gabbard, J. L., McGee, M., Durbin, J. and King, T. (1999). User-centered design and evaluation of a real-time battlefield visualization virtual environment. In *Proceedings IEEE Virtual Reality (Cat. No. 99CB36316)*, 96–103. https://doi.org/10.1109/VR.1999.756939.

Howard, D. and MacEachren, A. M. (1996). Interface Design for Geographic Visualization: Tools for Representing Reliability. *Cartography and Geographic Information Systems*, *23*(2), 59–77. https://doi.org/10.1559/152304096782562109

Hruby, F., Castellanos, I. and Ressl, R. (2021). Cartographic Scale in Immersive Virtual Environments. *KN - Journal of Cartography and Geographic Information*, *71*(1), 45–51. https://doi.org/10.1007/s42489-020-00055-y.

Huang, H., Schmidt, M. and Gartner, G. (2012). Spatial knowledge acquisition with mobile maps, augmented reality and voice in the context of GPS-based pedestrian navigation: Results from a field test. *Cartography and Geographic Information Science*, *39*(2), 107–116. https://doi.org/10.1559/15230406392107.

Hugues, O., Cieutat, J.-M. and Guitton, P. (2011). GIS and Augmented Reality: State of the Art and Issues. In: Furht, B. (eds) *Handbook of Augmented Reality*, 721–740. Springer New York. https://doi.org/10.1007/978-1-4614-0064-6_33.

Hwang, W. and Salvendy, G. (2010). Number of people required for usability evaluation: The 10±2 rule. *Communications of the ACM*, *53*(5), 130–133. https://doi.org/10.1145/1735223.1735255.

Häkkilä, J., Rantakari, J., Virtanen, L., Colley, A. and Cheverst, K. (2016). Projected fiducial markers for dynamic content display on guided tours. In *CHI EA '16: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2490–2496. https://doi.org/10.1145/2851581.2892345.

International Organization for Standardization (ISO). (2014). ISO 9186-1:2014; Graphical Symbols—Test Methods—Part 1: Method for Testing Comprehensibility. Available at: https://www.iso.org/standard/59226.html (Accessed: 10 January 2026).

International Organization for Standardization (ISO). (2018). ISO 9241-11:2018; Ergonomics of Human-System Interaction—Part 11: Usability: Definitions and concepts. Available at: https://www.iso.org/standard/63500.html (Accessed: 10 January 2026).

International Organization for Standardization (ISO). (2019a). ISO 9241-210:2019; Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems. Available at: https://www.iso.org/standard/77520.html (Accessed: 10 January 2026).

International Organization for Standardization (ISO). (2019b). ISO 9241-220:2019; Ergonomics of human-system interaction — Part 220: Processes for enabling, executing and assessing human-centred design within organizations. Available at: https://www.iso.org/standard/63462.html (Accessed: 10 January 2026).

Irshad, S. and Rambli, D. R. A. (2015). Preliminary user experience framework for designing mobile augmented reality technologies. In *2015 4th International Conference on Interactive Digital Media (ICIDM)*, 1–4. https://doi.org/10.1109/IDM.2015.7547833.

Irshad, S. and Awang, D. R. B. (2018). A UX Oriented Evaluation approach for Mobile Augmented Reality Applications. In *MoMM2018: Proceedings of the 16th*

International Conference on Advances in Mobile Computing and Multimedia, 108–112. https://doi.org/10.1145/3282353.3282357.

Irshad, S., Rambli, D. R. A. and Sulaiman, S. (2020). Design and implementation of user experience model for augmented reality systems. In *MoMM '20: Proceedings of the 18th International Conference on Advances in Mobile Computing & Multimedia*, 48–57. https://doi.org/10.1145/3428690.3429169.

Ishikawa, T and Montello, D. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places☆. *Cognitive Psychology*, *52*(2), 93–129. https://doi.org/10.1016/j.cogpsych.2005.08.003.

Ishikawa, T., Fujiwara, H., Imai, O. and Okabe, A. (2008). Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology*, *28*(1), 74–82. https://doi.org/10.1016/J.JENVP.2007.09.002.

Ishikawa, T. (2019). Satellite Navigation and Geospatial Awareness: Long-Term Effects of Using Navigation Tools on Wayfinding and Spatial Orientation. *Professional Geographer*, *71*(2), 197–209. https://doi.org/10.1080/00330124.2018.1479970.

Jancewicz, K. and Borowicz, D. (2017). Tourist maps – definition, types and contents. *Polish Cartographical Review*, *49*(1), 27–41. https://doi.org/10.1515/PCR-2017-0003.

Jenny, B. (2012). Adaptive Composite Map Projections. *IEEE Transactions on Visualization and Computer Graphics*, *18*(12), 2575–2582. https://doi.org/10.1109/TVCG.2012.192.

Juřík, V., Herman, L. and Šašinka, Č. (2018). Interaction Primitives in 3D Geovisualizations. In *Useful Geography: Transfer from Research to Practice. Proceedings of the 25th Central European Conference*, 294-303. Available at: https://www.ceeol.com/search/chapter-detail?id=1113297 (Accessed: 10 January 2026).

Kapaj, A., Lanini-Maggi, S. and Fabrikant, S. I. (2021). The influence of landmark visualization style on expert wayfinders' visual attention during a real-world navigation task. In *GIScience 2021 Short Paper Proceedings*. https://doi.org/10.25436/E2NP44.

Kato, H. and Billinghurst, M. (1999). Marker tracking and HMD calibration for a video-based augmented reality conferencing system. In *Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)*, 85–94. https://doi.org/10.1109/IWAR.1999.803809.

Keil, J., Korte, A., Ratmer, A., Edler, D. and Dickmann, F. (2020a). Augmented Reality (AR) and Spatial Cognition: Effects of Holographic Grids on Distance Estimation and Location Memory in a 3D Indoor Scenario. *PFG - Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, *88*(2), 165–172. https://doi.org/10.1007/s41064-020-00104-1.

Kessler, F. (2000). Focus Groups as a Means of Qualitatively Assessing the U-Boat Narrative. *Cartographica*, *37*(4), 33–60. https://doi.org/10.3138/C631-1LM4-14J3-1674.

Koláčný, A. (1969). Cartographic Information—a Fundamental Concept and Term in Modern Cartography. *The Cartographic Journal*, *6*(1), 47–49. https://doi.org/10.1179/CAJ.1969.6.1.47.

Konečný, M. and Staněk, K. (2010). Adaptive cartography and geographical education. *International Research in Geographical and Environmental Education*, *19*(1), 75–78. https://doi.org/10.1080/10382041003602977.

Konstantinou, E. N., Skopeliti, A. and Nakos, B. (2023). POI Symbol Design in Web Cartography—A Comparative Study. *ISPRS International Journal of Geo-Information*, *12*(7), 254. https://doi.org/10.3390/ijgi12070254.

Korcz, N., Ciesielski, M., Kamińska, A., Choromański, K., Gotlib, D., Stefán, F. and Taczanowska, K. (2024). The use of digital tools in forest tourism and recreation - Experiences from Warsaw agglomeration in Poland. *Trees, Forests and People*, *18*, 100697. https://doi.org/10.1016/j.tfp.2024.100697.

Kostelnick, J. C., Dobson, J. E., Egbert, S. L. and Dunbar, M. D. (2008). Cartographic Symbols for Humanitarian Demining. *The Cartographic Journal*, *45*(1), 18–31. https://doi.org/10.1179/000870408X276585.

Kovačević, D., Brozović, M. and Možina, K. (2024). Comprehension of City Map Pictograms Designed for Specific Tourists' Needs. *ISPRS International Journal of Geo-Information*, *13*(4), 137. https://doi.org/10.3390/ijgi13040137.

Kraak, M. J. and Ormeling, F. (2010). *Cartography: visualization of geospatial data* (3rd ed.). Prentice Hall.

Krauß, V., Jasche, F., Saßmannshausen, S. M., Ludwig, T. and Boden, A. (2021). Research and Practice Recommendations for Mixed Reality Design – Different Perspectives from the Community. In VRST '21: Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology, 1–13. https://doi.org/10.1145/3489849.3489876.

Krug, S. (2014). *Don't Make Me Think, Revisited A Common Sense Approach to Web (and Mobile) Usability* (3rd ed.). New Riders.

Kruijff, E., Swan, J. E. and Feiner, S. (2010). Perceptual issues in augmented reality revisited. In *2010 IEEE International Symposium on Mixed and Augmented Reality*, 3–12. https://doi.org/10.1109/ISMAR.2010.5643530.

Kuparinen, L. (2016). Validation and Extension of the Usability Heuristics for Mobile Map Applications. In *International Conference on Cartography and GIS (6ICC&GIS)*. Available at: https://www.researchgate.net/publication/304783525_Validation_and_Extension_of_the_Usability_Heuristics_for_Mobile_Map_Applications (Accessed: 10 January 2026).

Labrie, A. and Cheng, J. (2020). Adapting Usability Heuristics to the Context of Mobile Augmented Reality. In *UIST 2020 - Adjunct Publication of the 33rd Annual ACM Symposium on User Interface Software and Technology*, 4–6. https://doi.org/10.1145/3379350.3416167.

Laha, B., Bowman, D. A., Laidlaw, D. H. and Socha, J. J. (2015). A classification of user tasks in visual analysis of volume data. In *2015 IEEE Scientific Visualization Conference (SciVis)*, 1–8. https://doi.org/10.1109/SciVis.2015.7429485.

Lakehal, A., Lepreux, S., Efstratiou, C., Kolski, C. and Nicolaou, P. (2023). Spatial Knowledge Acquisition for Pedestrian Navigation: A Comparative Study between Smartphones and AR Glasses. *Information*, *14*(7), 353. https://doi.org/10.3390/INFO14070353.

Lampropoulos, G., Keramopoulos, E., Diamantaras, K. and Evangelidis, G. (2022). Augmented Reality and Virtual Reality in Education: Public Perspectives, Sentiments, Attitudes, and Discourses. *Education Sciences*, *12*(11) 798. https://doi.org/10.3390/educsci12110798.

Lapaine, M., Midtbø, T., Gartner, G., Bandrova, T., Wang, T. and Shen, J. (2021). Definition of the Map. In *Advances in Cartography and GIScience of the ICA*, *3*(9), 1–6. https://doi.org/10.5194/ica-adv-3-9-2021.

Law, R., Chan, I. C. C. and Wang, L. (2018). A comprehensive review of mobile technology use in hospitality and tourism. *Journal of Hospitality Marketing & Management*, *27*(6), 626–648. https://doi.org/10.1080/19368623.2018.1423251.

Lazar, J., Heidi Feng, J. and Hochheiser, H. (2017). *Research Methods in Human-Computer Interaction* (2nd ed.). Morgan Kaufmann.

Leung, L.-F. and Li, Z. (2002). Experimental Evaluation of the Effectiveness of Graphic Symbols on Tourist Maps. *Cartography*, *31*(1), 11–20. https://doi.org/10.1080/00690805.2002.9714176.

Liarokapis, F., Greatbatch, I., Mountain, D., Gunesh, A., Brujic-Okretic, V. and Raper, J. (2005). Mobile augmented reality techniques for geovisualisation. In *Ninth International Conference on Information Visualisation (IV'05)*, 745–751. https://doi.org/10.1109/IV.2005.79.

Lindner, C., Ortwein, A., Staar, K. and Rienow, A. (2021). Different Levels of Complexity for Integrating Textured Extra-terrestrial Elevation Data in Game Engines for Educational Augmented and Virtual Reality Applications. *KN - Journal of Cartography and Geographic Information*, *71*(4), 253–267. https://doi.org/10.1007/S42489-021-00090-3.

Liu, B., Ding, L. and Meng, L. (2021). Spatial knowledge acquisition with virtual semantic landmarks in mixed reality-based indoor navigation. *Cartography and Geographic Information Science*, *48*(4), 305–319. https://doi.org/10.1080/15230406.2021.1908171.

Livingston, M. A. (2005). Projects in VR: Evaluating human factors in augmented reality systems. In *IEEE Computer Graphics and Applications*, *25*(6), 6–9. https://doi.org/10.1109/MCG.2005.130.

Lovrić, P. (1988). *Opća kartografija*. Sveučilišna naklada Liber.

MacEachren, A. M. (1994). Visualization in Modern Cartography: Setting the Agenda. *Modern Cartography Series*, 2, 1–12. https://doi.org/10.1016/B978-0-08-042415-6.50008-9.

MacEachren, A. M. (1995). *How maps work: representation, visualization, and design*. The Guilford Press.

MacEachren, A. M. and Kraak, M.-J. (2001). Research Challenges in Geovisualization. *Cartography and Geographic Information Science*, *28*(1), 3–12. https://doi.org/10.1559/152304001782173970.

Maguire, M. (2001). Context of Use within usability activities. *International Journal of Human-Computer Studies*, *55*(4), 453–483. https://doi.org/10.1006/ijhc.2001.0486.

Marsh, L. S. and Haklay, M. M. (2010). Evaluation and Deployment. In *Interacting with Geospatial Technologies*, 199–221. https://doi.org/10.1002/9780470689813.CH10.

McCleary, G. F. (2009). Confronting the tourist map: Divergent purposes and disparate users. In *Proceedings of the ICA*. Available at: https://icaci.org/files/documents/ICC_proceedings/ICC2009/html/nonref/23_3.pdf (Accessed: 10 January 2026).

Medynska-Gulij, B. (2003). The Effect of Cartographic Content on Tourist Map Users. *Cartography*, *32*(2), 49–54. https://doi.org/10.1080/00690805.2003.9714252.

Medynska-Gulij, B. (2008). Point Symbols: Investigating Principles and Originality in Cartographic Design. *The Cartographic Journal*, *45*(1), 62–67. https://doi.org/10.1179/000870408X276602.

Mendoza-Ramírez, C. E., Tudon-Martinez, J. C., Félix-Herrán, L. C., Lozoya-Santos, J. de J. and Vargas-Martínez, A. (2023). Augmented Reality: Survey. *Applied Sciences*, *12*(18), 10491. https://doi.org/10.3390/app131810491.

Merino, L., Schwarzl, M., Kraus, M., Sedlmair, M., Schmalstieg, D. and Weiskopf, D. (2020). Evaluating Mixed and Augmented Reality: A Systematic Literature Review (2009-2019). Available at: http://arxiv.org/abs/2010.05988 (Accessed: 10 January 2026).

Microsoft. (2021). Mixed Reality documentation. Microsoft Learn (Mixed Reality). Available at: https://learn.microsoft.com/en-us/windows/mixed-reality/ (Accessed: 10 January 2026).

Milgram, P. and Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems*, E77-D(12). Available at: https://www.researchgate.net/publication/231514051_A_Taxonomy_of_Mixed_Reality_Visual_Displays (Accessed: 10 January 2026).

Ministry of Economy and Sustainable Development. (2020a). Knjiga standarda za korištenje jedinstvenog vizualnog identiteta zaštite prirode u Republici Hrvatskoj. Available at: https://narodne-novine.nn.hr/files/sluzbeni-dio/2020/81/NN-SL-2020-081-Prilog-1.pdf (Accessed: 10 January 2026).

Ministry of Economy and Sustainable Development. (2020b). Knjiga standarda za korištenje sustava signalizacije i interpretacije zaštićenih područja u Republici Hrvatskoj. Available at: https://narodne-novine.nn.hr/files/sluzbeni-dio/2020/81/NN-SL-2020-081-Prilog-2.pdf (Accessed: 10 January 2026).

Moacdieh, N. and Sarter, N. (2015). Display Clutter. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *57*(1), 61–100. https://doi.org/10.1177/0018720814541145.

Monmonier, M. and Gluck, M. (1994). Focus Groups for Design Improvement in Dynamic Cartography. *Cartography and Geographic Information Systems*, *21*(1), 37–47. https://doi.org/10.1559/152304094782563948.

Montello, D. R. (2002). Cognitive Map-Design Research in the Twentieth Century: Theoretical and Empirical Approaches. *Cartography and Geographic Information Science*, *29*(3), 283–304. https://doi.org/10.1559/152304002782008503.

Morrison, A., Oulasvirta, A., Peltonen, P., Lemmela, S., Jacucci, G., Reitmayr, G., Näsänen, J. and Juustila, A. (2009). Like bees around the hive: a comparative study of a mobile augmented reality map. In *CHI '09: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1889–1898. https://doi.org/10.1145/1518701.1518991.

Morrison, A., Mulloni, A., Lemmelä, S., Oulasvirta, A., Jacucci, G., Peltonen, P., Schmalstieg, D. and Regenbrecht, H. (2011). Collaborative use of mobile augmented reality with paper maps. *Computers and Graphics*, *35*(4), 789–799. https://doi.org/10.1016/j.cag.2011.04.009.

Morrison, J. (1976). The Science of Cartography and Its Essential Processes. *Cartographica*, *14*, 58-71.

Münzer, S., Zimmer, H. D., Schwalm, M., Baus, J. and Aslan, I. (2006). Computer-assisted navigation and the acquisition of route and survey knowledge. *Journal of Environmental Psychology*, *26*(4), 300–308. https://doi.org/10.1016/J.JENVP.2006.08.001.

Nielsen, J. (1993). *Usability Engineering* (1st ed.). Morgan Kaufmann.

Norman, D. A. and Draper, S. W. (1986). *User Centered System Design: New Perspectives on Human-computer Interaction*. CRC Press.

Norman, D.A. (2013). *Design of Everyday Things*. Basic Books.

Norrie, M. and Signer, B. (2005). Overlaying Paper Maps with Digital Information Services for Tourists. In: Frew, A.J. (eds) *Information and Communication Technologies in Tourism 2005*, 23–33. Springer. https://doi.org/10.1007/3-211-27283-6_3.

Official Gazette 81/20. Ordinance on the unique visual identity of nature conservation in the Republic of Croatia. Available at: https://narodne-novine.nn.hr/clanci/sluzbeni/2020_07_81_1518.html (Accessed: 10 January 2026).

Official Gazette 80/13, 15/18, 14/19, 127/19, 155/23. The Law on Nature Protection. Available at: https://narodne-novine.nn.hr/clanci/sluzbeni/2013_06_80_1658.html (Accessed: 10 January 2026).

Olberding, H. and Vetter, M. (2023). Dynamic 3D-Cartographic Symbols for VR Geovisualizations. *KN - Journal of Cartography and Geographic Information*, *73*(4), 265–275. https://doi.org/10.1007/s42489-023-00153-7.

Olsson, T., Kärkkäinen, T., Lagerstam, E. and Ventä-Olkkonen, L. (2012). User evaluation of mobile augmented reality scenarios. *Journal of Ambient Intelligence and Smart Environments*, *4*(1), 29–47. https://doi.org/10.3233/AIS-2011-0127.

Ooms, K., De Maeyer, P., Fack, V., Van Assche, E. and Witlox, F. (2012). Interpreting maps through the eyes of expert and novice users. *International Journal of Geographical Information Science*, *26*(10), 1773–1788. https://doi.org/10.1080/13658816.2011.642801.

Ooms, K., Coltekin, A., De Maeyer, P., Dupont, L., Fabrikant, S., Incoul, A., Kuhn, M., Slabbinck, H., Vansteenkiste, P. and Van der Haegen, L. (2015). Combining user logging with eye tracking for interactive and dynamic applications. *Behavior Research Methods*, *47*(4), 977–993. https://doi.org/10.3758/s13428-014-0542-3.

Ostrowski, W. (2008). Stages of development of cartography as a science. *Miscellanea Geographica*, *13*(1), 267–276. https://doi.org/10.2478/MGRSD-2008-0027.

Paelke, V. and Sester, M. (2009). Augmented paper maps: Exploring the design space of a mixed reality system. *ISPRS Journal of Photogrammetry and Remote Sensing*, *65*(3), 256–265. https://doi.org/10.1016/j.isprsjprs.2009.05.006.

Pavelka, K. and Landa, M. (2024). Using Virtual and Augmented Reality with GIS Data. *ISPRS International Journal of Geo-Information*, *13*(7), 241. https://doi.org/10.3390/ijgi13070241.

Petchenik, B. (1975). *Cognition in cartography*. *Cartographica*, *14*, 117-128.

Poslončec-Petrić, V., Vuković, V., Bačić, Ž., Kljajić, I. (2023). Use of Augmented Reality to Present Archaeological Contents. In: Ademović, N., Kevrić, J., Akšamija, Z. (eds) *Advanced Technologies, Systems, and Applications VIII. IAT 2023*. Lecture Notes in Networks and Systems, *644*. Springer, Cham. https://doi.org/10.1007/978-3-031-43056-5_15.

Ratajski, L. (1971). The methodological basis of the standardisation of signs on economic maps. *International Yearbook of Cartography*, *11*, 137–159.

Rehman, U. and Cao, S. (2017). Augmented-Reality-Based Indoor Navigation: A Comparative Analysis of Handheld Devices Versus Google Glass. In *IEEE Transactions on Human-Machine Systems*, *47*(1), 140–151. https://doi.org/10.1109/THMS.2016.2620106.

Reichenbacher, Tumasch. (2001). Adaptive concepts for a mobile cartography. *Journal of Geographical Sciences*, *11*(Suppl 1), 43–53. https://doi.org/10.1007/BF02837443.

Reichenbacher, T. (2003). Adaptive Methods for Mobile Cartography. In *Proceedings of the 21st International Cartographic Conference (ICC)*, 1311–1322. Available at: https://www.researchgate.net/publication/245199429_Adaptive_Methods_for_Mobile_Cartography (Accessed: 10 January 2026).

Reichenbacher, T. (2004). Mobile cartography: adaptive visualisation of geographic information on mobile devices. PhD Thesis, Technical University of Munich. Available at: https://mediatum.ub.tum.de/doc/601066/601066.pdf (Accessed: 10 January 2026).

Reichenbacher, T. and Bartling, M. (2023). Adaptivity as a key feature of mobile maps in the digital era. *Frontiers in Communication*, *8*. https://doi.org/10.3389/FCOMM.2023.1258851.

Reilly, D., Rodgers, M., Argue, R., Nunes, M. and Inkpen, K. (2006). Marked-up maps: combining paper maps and electronic information resources. *Personal and Ubiquitous Computing*, *10*(4), 215–226. https://doi.org/10.1007/s00779-005-0043-6.

Reitmayr, G., Eade, E. and Drummond, T. (2005). Localisation and interaction for augmented maps. In *Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'05)*, 120–129. https://doi.org/10.1109/ISMAR.2005.39.

Richardson, A. E., Montello, D. R. and Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition*, *27*(4), 741–750. https://doi.org/10.3758/BF03211566.

Robinson, A. H. (1952). *The look of maps: an examination of cartographic design*. University of Wisconsin Press. https://doi.org/10.2307/3105198.

Robinson, A. H. and Petchenik, B. B. (1976). *The nature of maps : essays toward understanding maps and mapping*. University of Chicago Press. Available at: https://books.google.com/books/about/The_Nature_of_Maps.html?id=b7FzQgAACAAJ (Accessed: 10 January 2026).

Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G. and MacEachren, A. M. (2005). Combining Usability Techniques to Design Geovisualization Tools for Epidemiology. *Cartography and Geographic Information Science*, *32*(4), 243–255. https://doi.org/10.1559/152304005775194700.

Robinson, A. C., MacEachren, A. M. and Roth, R. E. (2011). Designing a web-based learning portal for geographic visualization and analysis in public health. *Health Informatics Journal*, *17*(3), 191–208. https://doi.org/10.1177/1460458211409718.

Robinson, A. C., Kettunen, P., Delazari, L. and Çöltekin, A. (2023). New directions for the state of the art and science in Cartography. *International Journal of Cartography*, *9*(2), 143–149. https://doi.org/10.1080/23729333.2023.2216334.

Rosenholtz, R., Li, Y. and Nakano, L. (2007). Measuring visual clutter. *Journal of Vision*, *7*(2), 17. https://doi.org/10.1167/7.2.17.

Roth, R. and Harrower, M. (2008). Addressing Map Interface Usability: Learning from the Lakeshore Nature Preserve Interactive Map. *Cartographic Perspectives*, *46*(60), 46–66. https://doi.org/10.14714/CP60.231.

Roth, R E., Ross, K. S., Finch, B. G., Luo, W. and Maceachren, A. M. (2010). A user-centered approach for designing and developing spatiotemporal crime analysis tools. Available at: https://giscience2010.org/pdfs/paper_238.pdf (Accessed: 10 January 2026).

Roth, R. (2013). Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science*, 6, 59–115. https://doi.org/10.5311/JOSIS.2013.6.105.

Roth, R., Ross, K. and MacEachren, A. (2015). User-Centered Design for Interactive Maps: A Case Study in Crime Analysis. *ISPRS International Journal of Geo-Information*, *4*(1), 262–301. https://doi.org/10.3390/ijgi4010262.

Roth, R. (2015). Interactivity and Cartography: A Contemporary Perspective on User Interface and User Experience Design from Geospatial Professionals. *Cartographica*, *50*(2), 94–115. https://doi.org/10.3138/CART.50.2.2427.

Roth, R., Çöltekin, A., Delazari, L., Filho, H. F., Griffin, A., Hall, A., Korpi, J., Lokka, I., Mendonça, A., Ooms, K. and van Elzakker, C. P. J. M. (2017). User studies in cartography: opportunities for empirical research on interactive maps and visualizations. *International Journal of Cartography*, *3*(sup1), 61–89. https://doi.org/10.1080/23729333.2017.1288534.

Roth, R. (2019). How do user-centered design studies contribute to cartography? *Geografie*, *124*(2), 133–161. https://doi.org/10.37040/geografie2019124020133.

Roth, R., Griffin, A. L. and Huang, H. (2024). Mobile Cartography: An International Cartographic Association (ICA) collective research agenda for mobile-first and responsive maps & visualizations. *Journal of Location Based Services*, *18*(4), 335–349. https://doi.org/10.1080/17489725.2024.2406820.

Roth, R., Çöltekin, A., Delazari, L., Denney, B., Mendonça, A., Ricker, B. A., Shen, J., Stachoň, Z. and Wu, M. (2024). Making maps & visualizations for mobile devices: A research agenda for mobile-first and responsive cartographic design. *Journal of Location Based Services*, *18*(4), 408–478. https://doi.org/10.1080/17489725.2023.2251423.

Rubin, J. and Chisnell D. (2008). *Handbook of Usability Testing : How to Plan, Design, and Conduct Effective Tests* (2nd ed.). Wiley Publishing, Inc.

Ruginski, I. T., Creem-Regehr, S. H., Stefanucci, J. K. and Cashdan, E. (2019). GPS use negatively affects environmental learning through spatial transformation abilities.

Journal of Environmental Psychology, *64*, 12–20. https://doi.org/10.1016/j.jenvp.2019.05.001.

Salichtchev, K. A. (1970). The subject and method of cartography: contemporary views. *Cartographica*, 7(2), 77–87. https://doi.org/10.3138/92G4-N258-7879-1796.

Sarjakoski, L. T. and Nivala, A. M. (2005). Adaptation to Context — A Way to Improve the Usability of Mobile Maps. In: Meng, L., Reichenbacher, T., Zipf, A. (eds) *Map-based Mobile Services*, 107–123. Springer. https://doi.org/10.1007/3-540-26982-7_8.

Sasaki, R. and Yamamoto, K. (2019). A Sightseeing Support System Using Augmented Reality and Pictograms within Urban Tourist Areas in Japan. *ISPRS International Journal of Geo-Information*, *8*(9), 381. https://doi.org/10.3390/ijgi8090381.

Schmettow, M. (2012). Sample size in usability studies. *Communications of the ACM*, *55*(4), 64–70. https://doi.org/10.1145/2133806.2133824.

Schulz, M., Huiber, J. and Bandrova, T. (2021). A set of criteria for evaluating map application design in a mobile environment. In *Proceedings of the ICA*,*4*(97), 1–8. https://doi.org/10.5194/ica-proc-4-97-2021.

Schöning, J., Krüger, A. and Müller, J. (2006). Interaction of mobile camera devices with physical maps. In T. Pfeifer, A. Schmidt & W. Woo (Eds.), *Advances in Pervasive Computing 2006: Adjunct Proceedings of the 4th International Conference on Pervasive Computing*, 207, 121–124. Austrian Computer Society. Available at: http://joergmueller.info/pdf/Pervasive06SchoeningPhysicalMaps.pdf (Accessed: 10 January 2026).

Simon, J. (2023). Augmented Reality Application Development using Unity and Vuforia. *Interdisciplinary Description of Complex Systems: INDECS*, 21(1), 69–77. https://doi.org/10.7906/INDECS.21.1.6.

Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S. and Hedley, N. R. (2001). Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, *28*(1), 61–75. https://doi.org/10.1559/152304001782173998.

Slocum, T., Cliburn, D., Feddema, J. and Miller, J. (2003). Evaluating the usability of a tool for visualizing the uncertainty of the future global water balance. Cartography and Geographic Information Science, 30(4), 299–317.

Slocum, T. A. (2014). *Thematic cartography and geovisualization* (3rd ed.). Pearson.

Slocum, T. A., McMaster, R. B., Kessler, F. C. and Howard, H. H. (2023). *Thematic Cartography and Geovisualization* (4th ed.). CRC Press. https://doi.org/https://doi.org/10.1201/9781003150527.

Stroila, M., Mays, J., Gale, B. and Bach, J. (2011). Augmented transit maps. In *2011 IEEE Workshop on Applications of Computer Vision (WACV)*, 485–490. https://doi.org/10.1109/WACV.2011.5711543.

Stylianidis, E., Valari, E, Pagani, A, Carrillo, I, Kounoudes, A, Michail, K and Smagas, K. (2020). Augmented Reality Geovisualisation for Underground Utilities. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, *88*(2), 173–185. https://doi.org/10.1007/S41064-020-00108-X.

Swienty, O., Reichenbacher, T., Reppermund, S. and Zihl, J. (2008). The role of relevance and cognition in attention-guiding geovisualisation. *The Cartographic Journal*, *45*(3), 227–238. https://doi.org/10.1179/000870408X311422.

Taczanowska, K., González, L.-M., García-Massó, X., Zięba, A., Brandenburg, C., Muhar, A., Pellicer-Chenoll, M. and Toca-Herrera, J.-L. (2019). Nature-based Tourism or Mass Tourism in Nature? Segmentation of Mountain Protected Area Visitors Using Self-Organizing Maps (SOM). *Sustainability*, *11*(5), 1314. https://doi.org/10.3390/su11051314.

Taylor, D. R. F. (1991). Geographic information systems : the microcomputer and modern cartography. In Modern Cartography Series, 1, 1-20. https://doi.org/10.1016/B978-0-08-040277-2.50009-X.

Taylor, F. (1994). Perspectives on Visualization and Modern Cartography. In *Modern Cartography*, 333–341. Elsevier. https://doi.org/10.1016/B978-0-08-042415-6.50024-7.

Thi MT, T. and Parker, C. (2020). Designing exocentric pedestrian navigation for AR head mounted displays. In *CHI EA '20: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, 1-8. https://doi.org/10.1145/3334480.3382868.

Thorndyke, P. W. and Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, *14*(4), 560–589. https://doi.org/10.1016/0010-0285(82)90019-6.

Thrash, T. ;, Fabrikant, S. I. ;, Brügger, A. ;, Do, C., Tri, ;, Huang, H. ;, Richter, K.-F. ;, Lanini-Maggi, S. ;, Bertel, S. ;, Credé, S. ;, Gartner, G. ; and Münzer, S. (2019). The Future of Geographic Information Displays from GIScience, Cartographic, and Cognitive

Science Perspectives. In *14th International Conference on Spatial Information Theory (COSIT 2019)*, *142*, 19. https://doi.org/10.3929/ethz-b-000367391.

Touya, G., Hoarau, C. and Christophe, S. (2016). Clutter and Map Legibility in Automated Cartography: A Research Agenda. *Cartographica*, *51*(4), 198–207. https://doi.org/10.3138/cart.51.4.3132.

Tsou MH and Curran, J. M. (2008). User-Centered Design Approaches for Web Mapping Applications: A Case Study with USGS Hydrological Data in the United States. In M. P. Peterson (Ed.), *International Perspectives on Maps and the Internet* (Lecture Notes in Geoinformation and Cartography), 301–321. Springer. https://doi.org/10.1007/978-3-540-72029-4_20.

Turan, Z., Meral, E. and Sahin, I. F. (2018). The impact of mobile augmented reality in geography education: achievements, cognitive loads and views of university students. *Journal of Geography in Higher Education*, *42*(3), 427–441. https://doi.org/10.1080/03098265.2018.1455174.

Tyner, J. A. (2010). *Principles of map design*. Guilford Press.

Uttal, D. H. (2000). Seeing the big picture: map use and the development of spatial cognition. *Developmental Science*, *3*(3), 247–264. https://doi.org/10.1111/1467-7687.00119.

Van Elzakker, C. (2004). The use of maps in the exploration of geographic data. PhD Thesis, Utrecht University. Available at: https://dspace.library.uu.nl/handle/1874/1235 (Accessed: 10 January 2026).

Vanicek, T. and Popelka, S. (2023). The Think-Aloud Method for Evaluating the Usability of a Regional Atlas. *ISPRS International Journal of Geo-Information*, *12*(3), 95. https://doi.org/10.3390/ijgi12030095.

Vi, S., da Silva, T. S. and Maurer, F. (2019). User Experience Guidelines for Designing HMD Extended Reality Applications. In Lamas, D., Loizides, F., Nacke, L., Petrie, H., Winckler, M., Zaphiris, P. (eds) *Human-Computer Interaction – INTERACT 2019.* (Lecture Notes in Computer Science), *11749*. Springer. https://doi.org/10.1007/978-3-030-29390-1_18.

Wagemans, J., Elder, J. H., Kubovy, M., Palmer, S. E., Peterson, M. A., Singh, M. and von der Heydt, R. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and figure-ground organization. *Psychological Bulletin*, *138*(6), 1172–1217. https://doi.org/10.1037/A0029333.

Werner, P. A. (2018). Review of implementation of augmented reality into the georeferenced analogue and digital maps and images. *Information*, *10*(1). https://doi.org/10.3390/info10010012.

Wolf, M., Söbke, M. and Wehking, F. (2020). Mixed Reality Media-Enabled Public Participation in Urban Planning. In T. Jung, M. Claudia, T. Dieck & P. A. Rauschnabel (Eds.), *Augmented Reality and Virtual Reality Changing Realities in a Dynamic World*, 125–138. Springer. Available at: http://www.springer.com/series/10440 (Accessed: 10 January 2026).

Wolff, J. S. and Wogalter, M. S. (1998). Comprehension of Pictorial Symbols: Effects of Context and Test Method. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *40*(2), 173–186. https://doi.org/10.1518/001872098779480433.

Wüest, R. and Nebiker, S. (2018). Geospatial Augmented Reality for the interactive exploitation of large-scale walkable orthoimage maps in museums. In *Proceedings of the ICA*, *1*(124). https://doi.org/10.5194/ICA-PROC-1-124-2018.

Yan, L. and Lee, M. Y. (2015). Are tourists satisfied with the map at hand? *Current Issues in Tourism*, *18*(11), 1048–1058. https://doi.org/10.1080/13683500.2014.959904.

Yonov, N. (2019). School Atlas with Augmented Reality. In *Proceedings of the ICA*, *2*(150). https://doi.org/10.5194/ica-proc-2-150-2019.

Yonov, N. and Petkov, D. (2020). Augmented reality navigation map of mountain area. In *Proceedings Vol. 1, 8th International Conference on Cartography and GIS*, 668–677. Available at: https://www.researchgate.net/publication/344337226_AUGMENTED_REALITY_NAVIGATION_MAP_OF_MOUNTAIN_AREA (Accessed: 10 January 2026).

Yount, Z. F., Kass, S. J. and Arruda, J. E. (2022). Route learning with augmented reality navigation aids. *Transportation Research Part F: Traffic Psychology and Behaviour*, *88*, 132–140. https://doi.org/10.1016/j.trf.2022.05.019.

Yung, R. and Khoo-Lattimore, C. (2019). New realities: a systematic literature review on virtual reality and augmented reality in tourism research. *Current Issues in Tourism*, *22*(17), 2056–2081. https://doi.org/10.1080/13683500.2017.1417359.

Zajadacz, A. and Halik, Ł. (2024). User preferences of perspective and dimensionality of tourism space geovisualisation supporting orientation in a non-immersive virtual reality. *Quaestiones Geographicae*, *43*(3), 77–86. https://doi.org/10.14746/quageo-2024-0027.

Zou, N., Xu, Q., Wu, Y., Zhu, X. and Su, Y. (2023). An Automated Method for Generating Prefabs of AR Map Point Symbols Based on Object Detection Model. *ISPRS International Journal of Geo-Information*, *12*(11), 440. https://doi.org/10.3390/IJGI12110440.

Çöltekin, A., Garlandini, S., Heil, B. and Fabrikant, S. (2008). Evaluating the effectiveness of interactive map interface designs: a case study with eye movement analysis. In. *AutoCarto 2008*, 1–12. https://doi.org/10.5167/UZH-10125.

Çöltekin, Arzu, Griffin, A. L., Slingsby, A., Robinson, A. C., Christophe, S., Rautenbach, V., Chen, M., Pettit, C. and Klippel, A. (2020). Geospatial Information Visualization and Extended Reality Displays. In H. Guo, M. F. Goodchild & A. Annoni (Eds.), *Manual of Digital Earth*, 229–277. Springer Singapore. https://doi.org/10.1007/978-981-32-9915-3_7.

Çöltekin, Arzu, Lochhead, I., Madden, M., Christophe, S., Devaux, A., Pettit, C., Lock, O., Shukla, S., Herman, L., Stachoň, Z., Kubíček, P., Snopková, D., Bernardes, S. and Hedley, N. (2020). Extended reality in spatial sciences: A review of research challenges and future directions. *ISPRS International Journal of Geo-Information*, *9*(7). https://doi.org/10.3390/ijgi9070439.

Özogul, G. and Baran, G. G. (2016). Accessible tourism: the golden key in the future for the specialized travel agencies. *Journal of Tourism Futures*, *2*(1), 79–87. https://doi.org/10.1108/JTF-03-2015-0005.

Żyszkowska, W. (2015). Map perception: theories and research in the second half of the twentieth century. *Polish Cartographical Review*, *47*(4), 179–190. https://doi.org/10.1515/PCR-2015-0017.

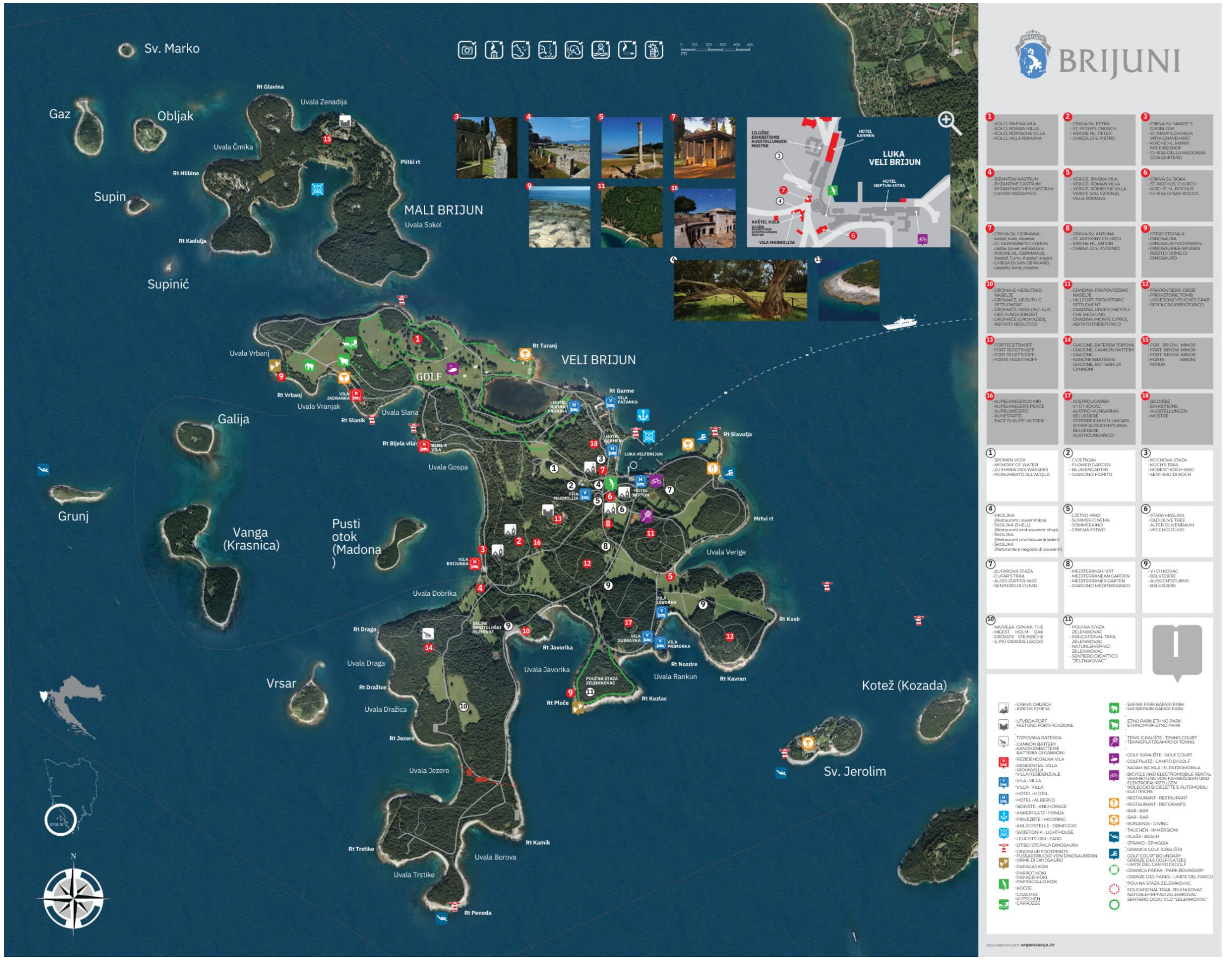
Żyszkowska, W. (2016). Visual features of cartographic representation in map perception. *Polish Cartographical Review*, *48*(1), 5–15. https://doi.org/10.1515/pcr-2016-0003.

APPENDICES

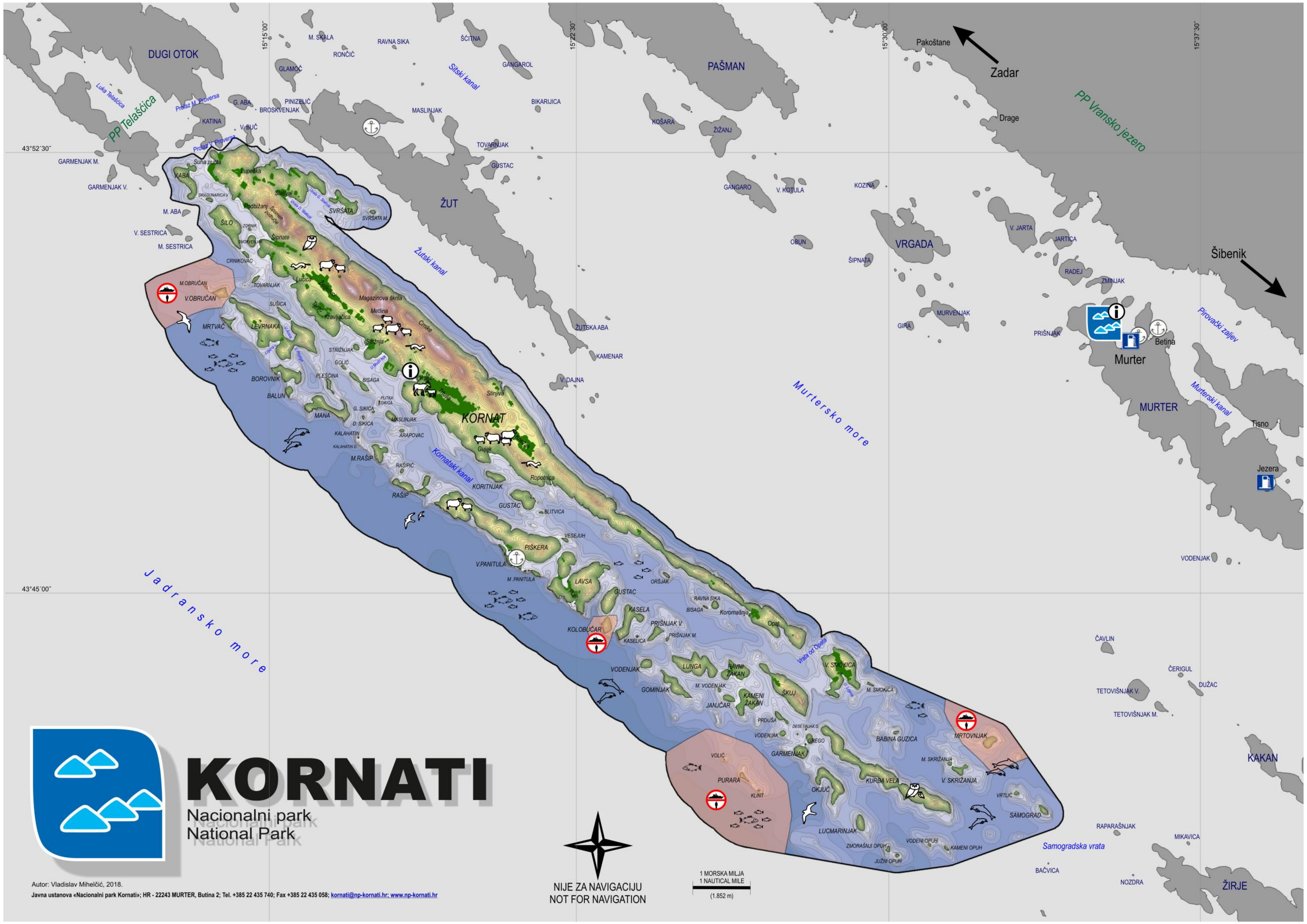
Appendix A – Phase 1: Competitive analysis of existing Croatian national park maps

A1. Analysed maps (n = 8) (full map sheets)

A1.1: National Park Brijuni map, original size 60 × 47 cm. Reproduced at enlarged size for reference; not to scale.

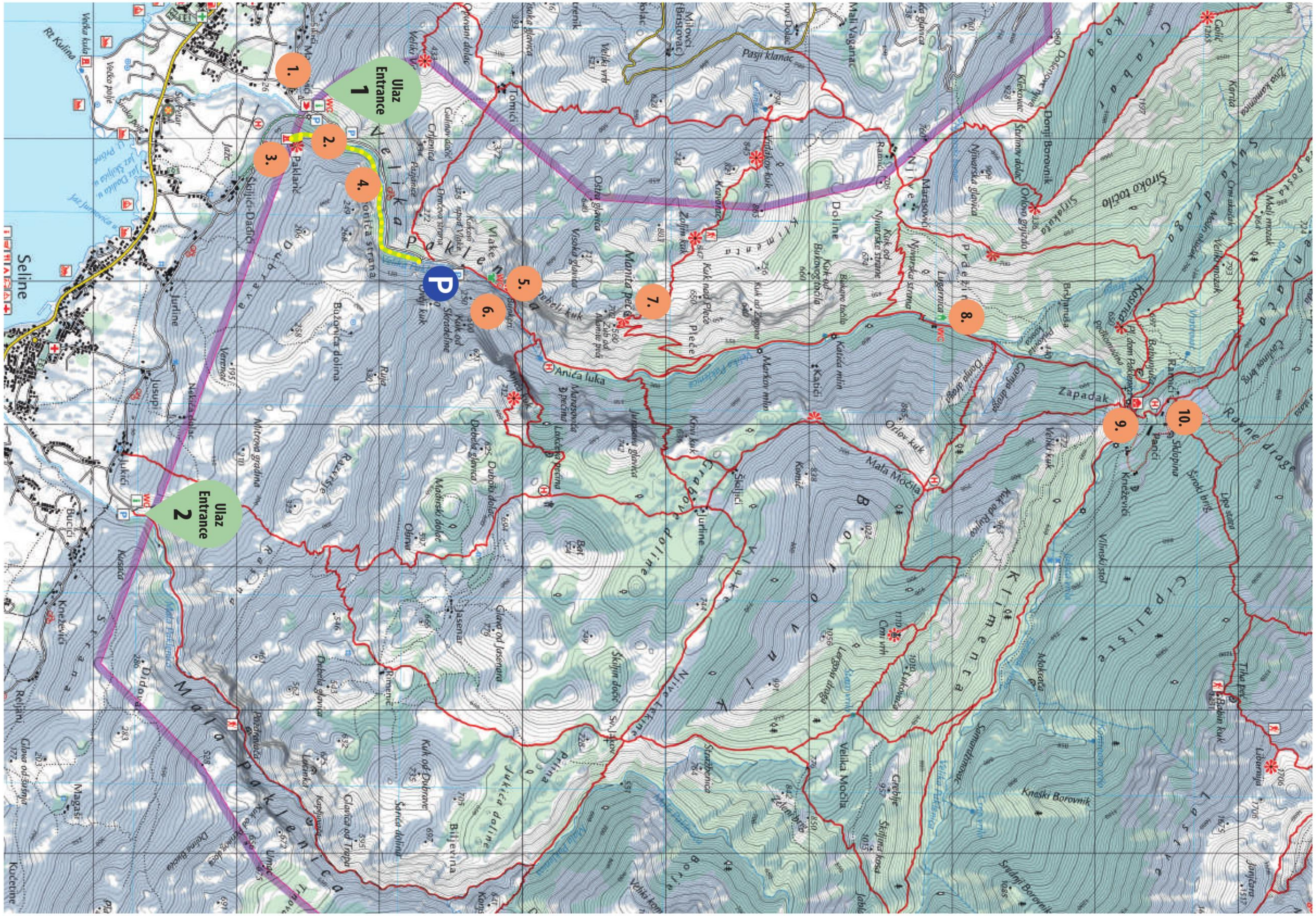


A1.2: National Park Kornati map, original size 42 × 30 cm. Reproduced at reduced size for reference; not to scale.

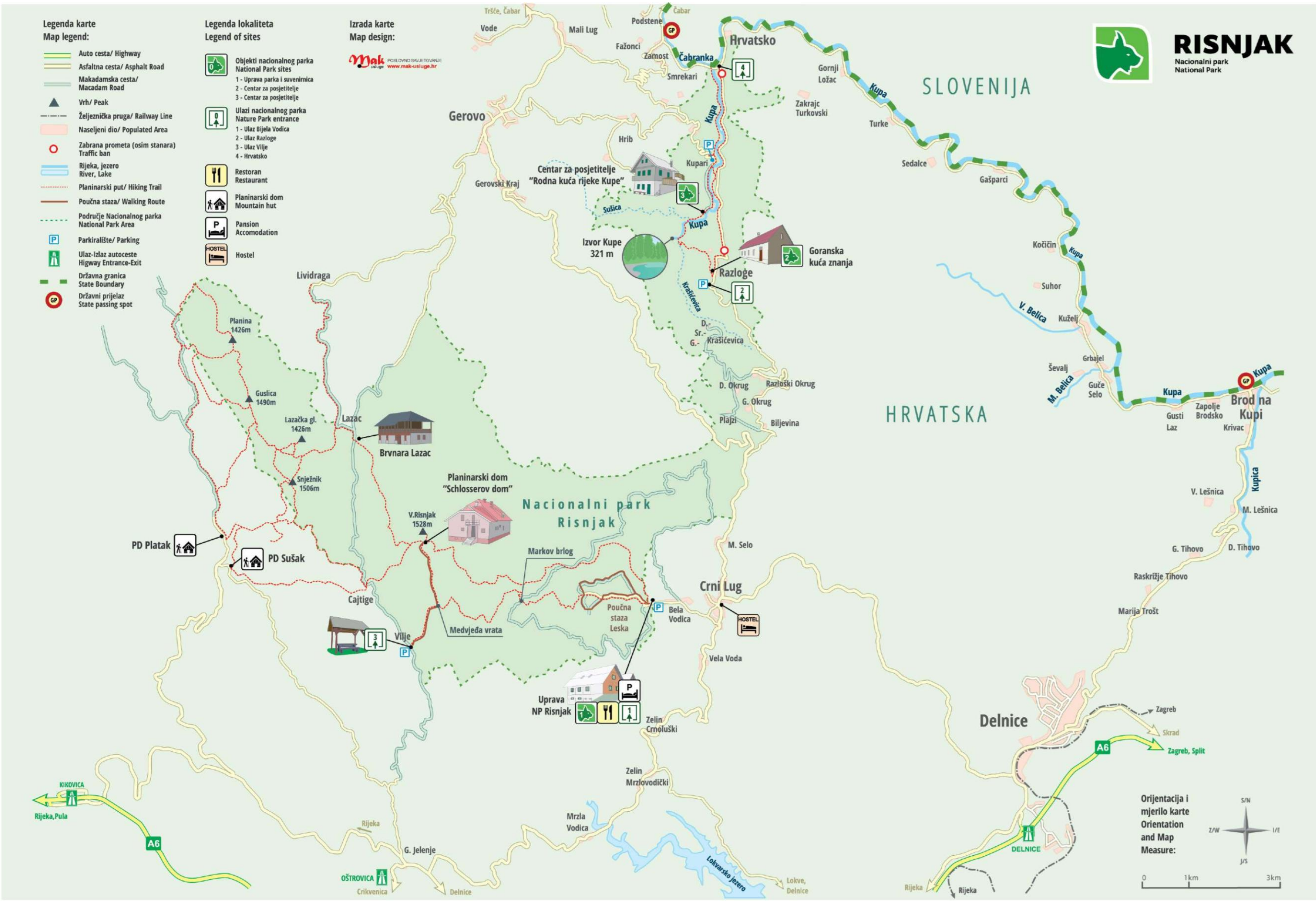


A1.3: National Park Mljet map, original size 68 × 98 cm. Reproduced at reduced size for reference; not to scale.

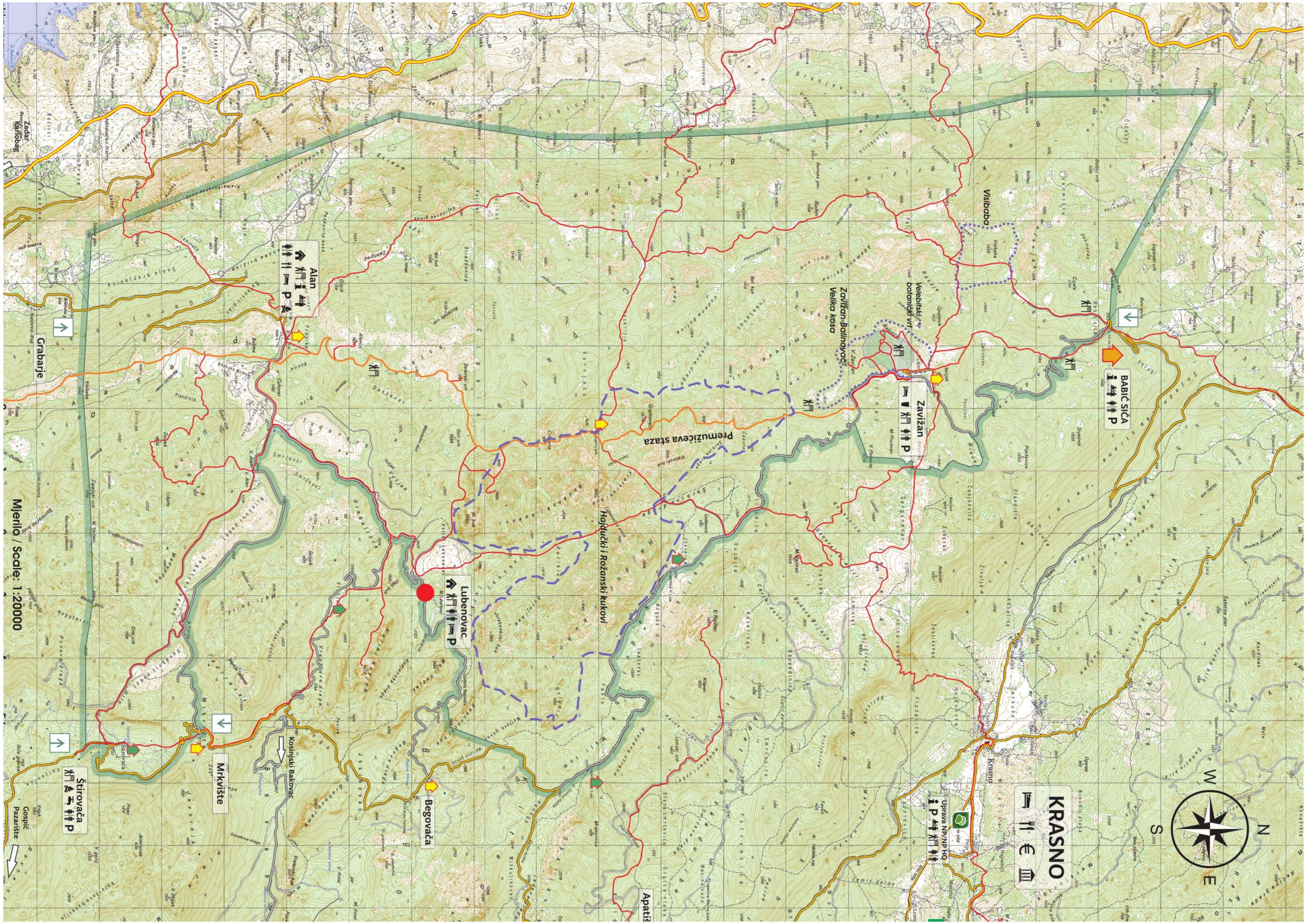
A1.4: National Park Paklenica map, original size 15 × 21 cm. Reproduced at enlarged size for reference; not to scale.



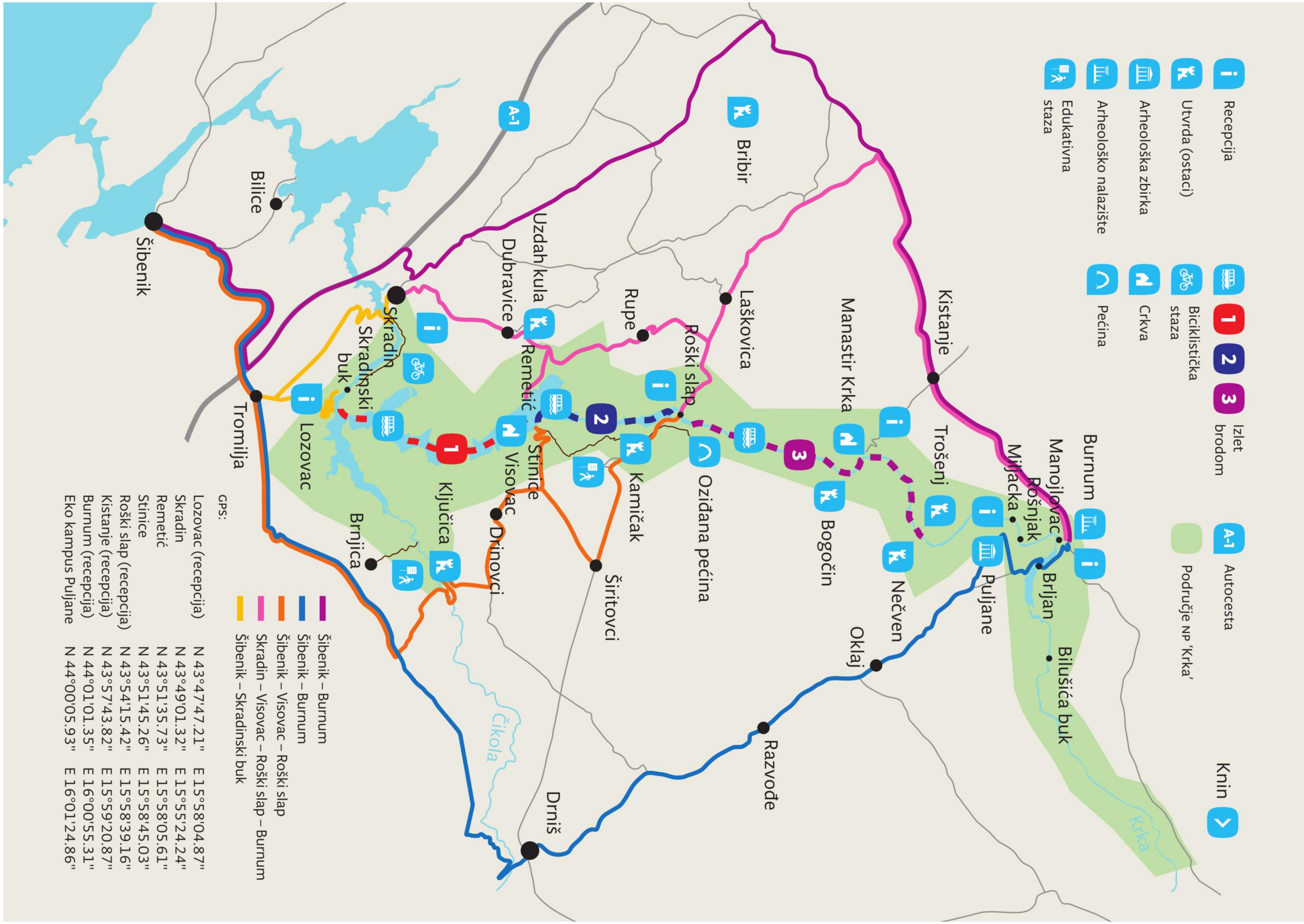
A1.5: National Park Risnjak map, original size 48 × 33 cm. Reproduced at reduced size for reference; not to scale.



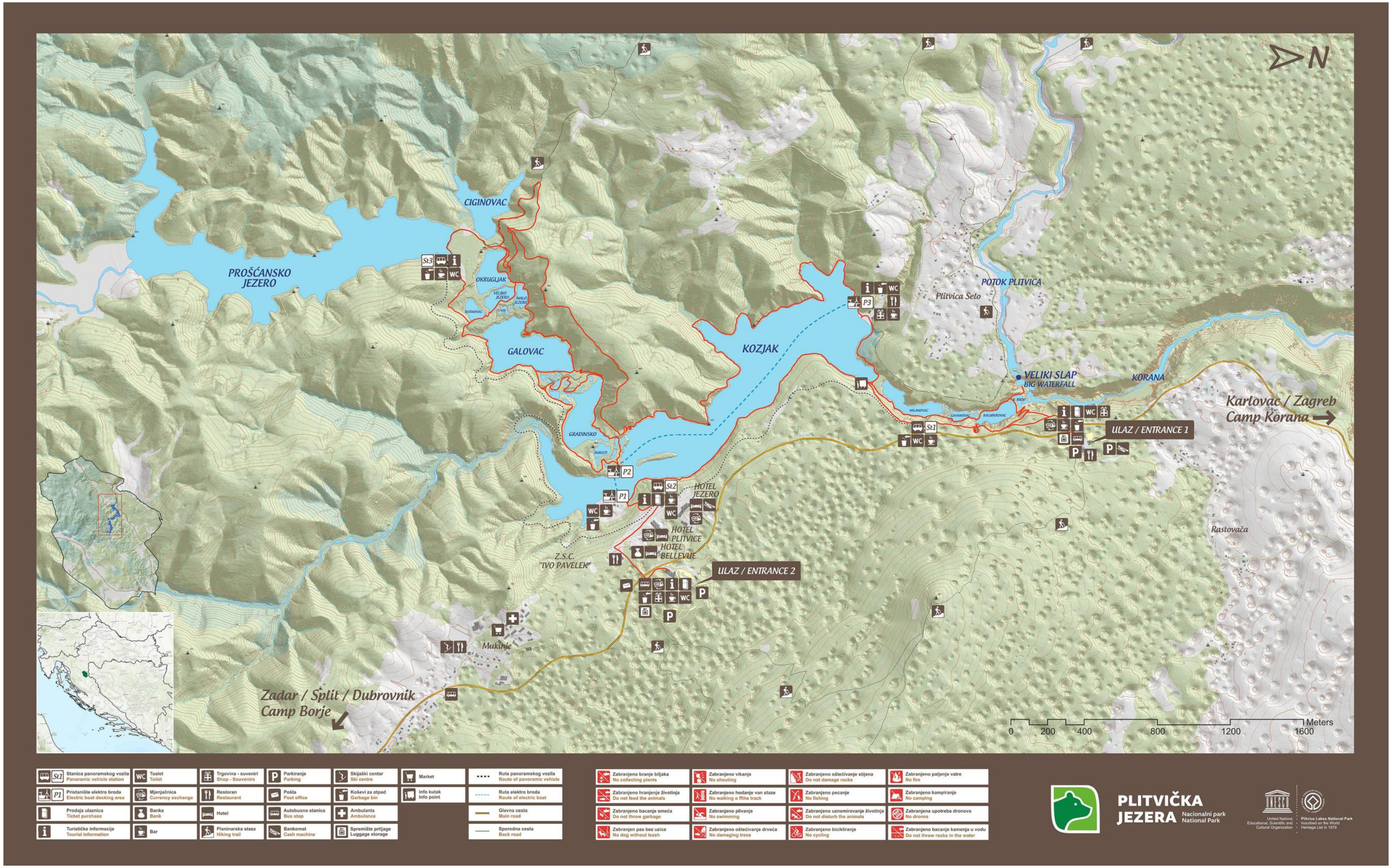
A1.6: National Park Sjeverni Velebit map, original size 21 × 30 cm. Reproduced at reduced size for reference; not to scale.



A1.7: National Park Krka map, original size 15 × 21 cm. Reproduced at enlarged size for reference; not to scale.



A1.8: National Park Plitvice lakes map, original size 106 × 66 cm. Reproduced at reduced size for reference; not to scale.



A2. Detailed Phase 1 map analyses (n = 8)

A2.1: National Park Brijuni map analysis

Map has a title „Brijuni“ in the upper right corner of the map, and there is no subtitle. It represents the entire area of Brijuni islands, therefore the national park area. It is oriented toward the North, which is common practice. The direction of North is displayed. The digital orthophoto is used as a background of the map, meaning that some map contents are not explicitly marked. Settlements are not represented in a cartographic manner, neither is relief or vegetation. A path along the islands is displayed as a grey line with two different thicknesses, along with a green line for educational trail. The ship line is represented as a white dotted line. The border of the national park and golf court are displayed. The scale is provided graphically. Altitudes and depths are not given. Map projection is not indicated, and the ellipsoid is unknown as well. Map doesn't contain a grid. The size of the map is 60 x 47 cm. A map legend is given in four languages (Croatian, English, German and Italian) for 24 symbols. They can be grouped by their colour and frame thickness. The lighthouse sign is the only one without a frame. Line objects are shown as circles - the boundary of the golf court and the boundary of the park. The paths are not indicated in the legend, except for the educational trail Zelenikovac. The ferry line is not indicated in the legend. The analysis of maps’ map graphics provided a lot of insight, the most important of which are summarized in the following paragraphs. Map symbols are of optimal size. Geographical names do not follow their contours and are written in odd font and colour (white). Graphical density seems optimal. Author, Publisher, Publication Date, Circulation and date sources are not indicated. The Map has no frame and does not contain any explanation text. It includes two inserted maps in the lower left corner (a map of Croatia and a map of Istria, where national park is located) and one inserted map of the harbour area in the higher right corner of the map. There are also images of the several locations which are indicated on the map by numbers. The list of those locations is provided under the title.

A2.2: National Park Kornati map analysis

The map title is given in the lower right corner of the map, which is quite unusual. It is followed by a subtitle “National Park” in four languages (Croatian, English, German and Italian). It is oriented toward North, with direction displayed. It represents the area of the national park, in colour, and its surroundings are visualized as shades of grey. Since there are no settlements on the islands, they are not displayed. Roads and boat lines are not given, but vegetation is. Relief is shown with contour lines and hypsometric colour scale. The border of the park area is also shown. The scale of the map is not provided, only length of one nautical mile is indicated. However, next to it is written that the map should not be used for navigation. Altitudes and depths are not indicated. Map projection is not indicated, and the ellipsoid is unknown as well. A map contains a graticule grid. The size of the map is 42 x 30 cm. This map doesn’t contain a map legend, which makes it difficult to read. There are four different symbols on a map, along with illustrations of animals like sheep and seagulls. Geographical names (toponyms) in the land are given in Times New Roman in thin black letters, and the ones show in the sea area are in the same font, but in blue colour. Map graphics and graphic density of the map are not satisfactory. Map was produced by Vladislav Mihelčić and published in 2018 by the National Park Kornati Institution. The Map has no frame and does not contain any explanation text.

A2.3: National Park Mljet map analysis

The map has a title “Mljet” in the upper right corner of the map. It is followed by a subtitle “National Park” in four languages (Croatian, English, German and Italian) and small flags representing each language. It represents the area of national park on the island of Mljet, so not the whole island. In line with customary practice, it is pointed northward. North arrow is also shown. The map represents the following objects: settlements, road lines, water bodies, relief, borders (areas) and geographical names (toponyms). Vegetation is not represented. Settlements are represented by individual buildings. Traffic lines include roads and ferry transport. The sea, lakes and springs are also represented. The relief is displayed with contour lines, contour interval is five meters, and peak heights are also given in meters. Considering borders (areas), border of national park is marked. Map scale is given graphically. Map projection is HTRS96 TM, and it contains graticule grid (meridians and parallels) in WGS84. The size of the map is 63 × 93 cm. There is a map legend for 25 symbols available in four languages: Croatian, English, German, and Italian. Their colour and frame thickness can be used to classify them. Traffic lines include state roads, asphalt road, macadam road, mountain bike route and walking trail, along with ferry line. A boat route on the Lakes is not shown on a map nor the legend but should be since it is one of the main activities for tourists in the park area. Toponyms are shown in accordance with cartographic rules. Map graphics and graphic density of the map is satisfactory. Generalization also seems to be good. Map was produced by Matej Kajinić and published in 2021 by the National Park Mljet Institution. Author copyright is also given on the map. Main source of the data is provided by national park institution. It includes one inserted map in the lower right corner, representing the Park area on a map of Dubrovnik-Neretva

County. Also, on the lower part of the map area are given instruction on what to always carry (bottle of water, good shoes) with themselves.

A2.4: National Park Paklenica map analysis

This map was one of rare ones provided by the national park institution in good resolution. It is a map in the national park catalogue. It does not have a title, scale, nor legend. The dimensions of a map are 15 x 21 cm. No projection or ellipsoid is provided. The map represents the following objects: settlements, road lines, sea, relief (with contour lines; height difference between two of them is five meters), vegetation and geographical names (toponyms). Border (area) of national park is not indicated. There are several symbols on the map that are derived from external sources, like entrances to the park. Also, there are some objects marked with numbers, but the map (nor catalogue) does not contain the list of those locations. Map graphics and graphic density of the map are not satisfactory. Author, Publication Date, Circulation and date sources are not indicated. It is published by the National Park Paklenica Institution. The Map has no frame and does not contain any explanation text.

A2.5: National Park Risnjak map analysis

Map has a title "Risnjak" in the upper right corner of the map. It is followed by a subtitle "National Park" in Croatian and English. It represents the area of the national park. It is oriented toward the North, which is common practice. The direction of North is displayed. The map represents the following objects: settlements, road and railway lines, water bodies, borders (areas) and geographical names (toponyms). Vegetation and relief are not represented. Settlements are represented using contours of constructed parts. The lakes and rivers are shown. The relief is not displayed but peak heights are given in meters. Considering borders (areas), border of national park is marked, together with the state border. Map scale is given graphically. Map projection and ellipsoid are unknown. The map does not contain a grid. The size of the map is 46 x 30 cm. A map legend is given in two languages (Croatian and English) for 22 symbols. They are divided into map legend and sites legend. The first one contains roads (highway, asphalt road, macadam road, hiking trail and walking route), railway route, populated area, peak symbol, traffic ban symbol, parking, highway entrance-exit, state passing spot, national park area, state boundary, river and lake symbols. Legend of sites contains national park sites like Visitor centre, national park entrances, along with restaurant, mountain hut, pansion and hostel symbols. Their colour and frame thickness are not related. What has been noticed is that the symbol size in the legend does not match the ones on the map itself.

The author of the map is Mak usluge company. Publisher, publication date, circulation and date sources are not indicated. The map has no frame and does not contain any explanation text. Certain parts of the map are missing. Illustrations of mountain huts are displayed along their locations.

A2.6: National Park Sjeverni Velebit map analysis

Map title is not given. The map is oriented toward North, with direction displayed. It represents the area of National Park Sjeverni Velebit. Regarding the map content, it displays the settlements as individual buildings. Traffic roads are displayed, but vegetation is not. Relief is shown with contour lines; the distance between them is 10 m. Border of the Park area is also shown, along with some other borders whose meanings are not clear. The scale of the map is provided numerically. Altitudes are indicated in meters. Map projection and the ellipsoid are not indicated. A map contains a grid. The size of the map is 21 x 30 cm. This map doesn't contain a map legend. There are 18 different symbols on a map, along with their illustrations in the thick black border showing the settlement name. It has been noticed that they are not the same size, which is not clear if it's intentionally or not. Geographical names (toponyms) are given in cartographic manner. Map graphics and graphic density of the map are not satisfactory. Author and Publisher data are not indicated. The Map has no frame and does not contain any explanation text.

A2.7: National Park Krka map analysis

The map has no title or subtitles. It represents the area of National Park Krka and its surroundings. It is pointed northward, but the North arrow is not shown. The map represents the following objects: settlements, road lines, water bodies, borders (areas) and geographical names (toponyms). Relief and vegetation are not displayed. Settlements are represented by point symbols of different sizes (probably according to their population). Traffic lines include roads and boat transport. The sea, lakes and rivers are also represented. The relief is not displayed. Considering borders (areas), border of national park is marked, and the area is represented as a green polygon. The dimensions of a map are 15 x 21 cm. No projection or ellipsoid is provided. Map scale is not given. Map legend shows 11 symbols, with the same size and colour, in Croatian. Boat routes are marked with different coloured numbers. Educational trail and bicycle route are marked as pictogram as well, and shown on the map, but are also displayed with the same thin dark line which is not indicated in any legend. Highways are marked as pictogram, and some car routes are visualized as lines of different colours and explained diagonal of the legend. One of them seems to be wrongly named. Other ones are not categorized and are not indicated in the legend. River names (Krka and Čikola) are the only toponyms shown. Map graphics and graphic density of the map is satisfactory. Generalization also seems to be good; maps display simplified representation of the area. Author, Publisher, Publication Date, Circulation and date sources are not indicated. The Map has no frame and does not contain any explanation text. Also, on the lower right part of the map area are given coordinates of, probably, Park entrances and reception offices.

A2.8: National Park Plitvice lakes map analysis

Map has a title „Plitvička jezera" in the lower right corner of the map, with subtitle "National Park" in Croatian and English. It represents the lake area of Plitvice lakes National Park. It has landscape orientation to the West, probably to fit all the lakes at the same height of the map reader. The direction of North is displayed. The map represents the following objects: settlements, road and boat lines, water bodies, relief, and geographical names (toponyms). Vegetation and borders (areas) are not represented. Settlements are represented by individual buildings. Traffic lines include roads and boat transport. The lakes and springs are also represented. The relief is displayed with digital relief model and contour lines with unknown height difference between them, and peak heights are given in meters. From the toponyms, only lake names are mentioned. The scale is provided graphically. Map projection is not indicated, and the ellipsoid is unknown as well. Map doesn't contain a grid. The size of the map is 103 x 56 cm. A map legend is given in Croatian and English for 26 symbols and 16 restriction signs. They are uniform by their colour and frame thickness. Map symbols are of optimal size. Lake names have different sizes, which makes them difficult to read. Graphical density seems optimal, except for relief representations which is bit overwhelming. Shading doesn't seem to be properly set. Author, Publisher, Publication Date, Circulation and date sources are not indicated. The Map has a thin frame and does not contain any explanation text. It includes two inserted maps in the lower left corner (a map of Croatia and a map of national park).

Appendix B – Phase 2: User needs assessment

B1. Study flyer / recruitment material (Phase 2)

B2. Phase 2 online questionnaire

The questionnaire is provided as exported from Microsoft Forms.

Symbols on a national park touristic map

This survey is part of PhD research conducted on a Chair of Cartography at the Faculty of Geodesy University of Zagreb regarding the usability of the cartographic products. No personal data is under scope of this research and will not be processed.

Privacy statement:

In accordance with Art.13 of L. Decree 196/03 and Art. 13 of Regulation (EU) 2016/679, your contact data are processed for this research only and in full compliance with the Privacy Code and the GDPR.

For any further questions you can contact me on icibilic@geof.hr.

*Mandatory

GENERAL INFORMATION

1*	Gender:	o Male o Female o Non-binary o Prefer not to say o Other
2*	Age:	o Under 18 years o 18-24 years o 25-34 years o 35-44 years o 45-54 years o 55-64 years o 65+ years
3*	Education:	o High school or equivalent o College or university o Associate or bachelor's degree o Master's degree or higher
4*	Home country:	*(open-ended)*
5*	Level of expertise in using Geographic Information Systems (GIS), maps, or other spatial tools:	o No Experience (I have never used GIS, maps, or any spatial tools) o Beginner (I have basic understanding and limited experience) o Intermediate (I am comfortable using these tools and can work independently on most tasks) o Advanced (I have extensive experience and can handle complex projects)

CARTOGRAPHIC QUESTIONS

6* Based on your preference, which symbol best represents the toilet?

- ○ 
- ○ 

7* According to your previous knowledge, what does this sign mean?

- ○ Anchorage
- ○ Mooring
- ○ No anchoring
- ○ Port
- ○ Other

8* Based on your preference, which sign best represents the viewpoint?

- ○ 
- ○ 
- ○ 
- ○ 
- ○ 
- ○ 

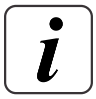
9* According to your previous knowledge, what does this sign mean? (i.e. bank, exchange office, ATM, etc.)

€

(open-ended)

10* Assign a symbol to its meaning in the order they appear!
Hint: you can have repeated meaning of the symbols!

(open-ended)

11*	According to your previous knowledge, what does this sign mean? 	o Information office o Reception o Offices o Ticket sales
12*	Assign a symbol to its meaning in the order they appear! Hint: you can have repeated meaning of the symbols! 	*(open-ended)*
13*	Which objects are the most important to you on the touristic map? Feel free to name as much as you want!	*(open-ended)*
14*	Which objects are the least important to you on the touristic map? Feel free to name as much as you want!	*(open-ended)*

FINAL TOUGHTS

15	General comment	*(open-ended)*
16	In case you would like to find out the final results of this research, please provide your email address!	*(open-ended)*

Appendix C – Phase 3: Conceptual design and AR prototyping

C1. Design requirements table

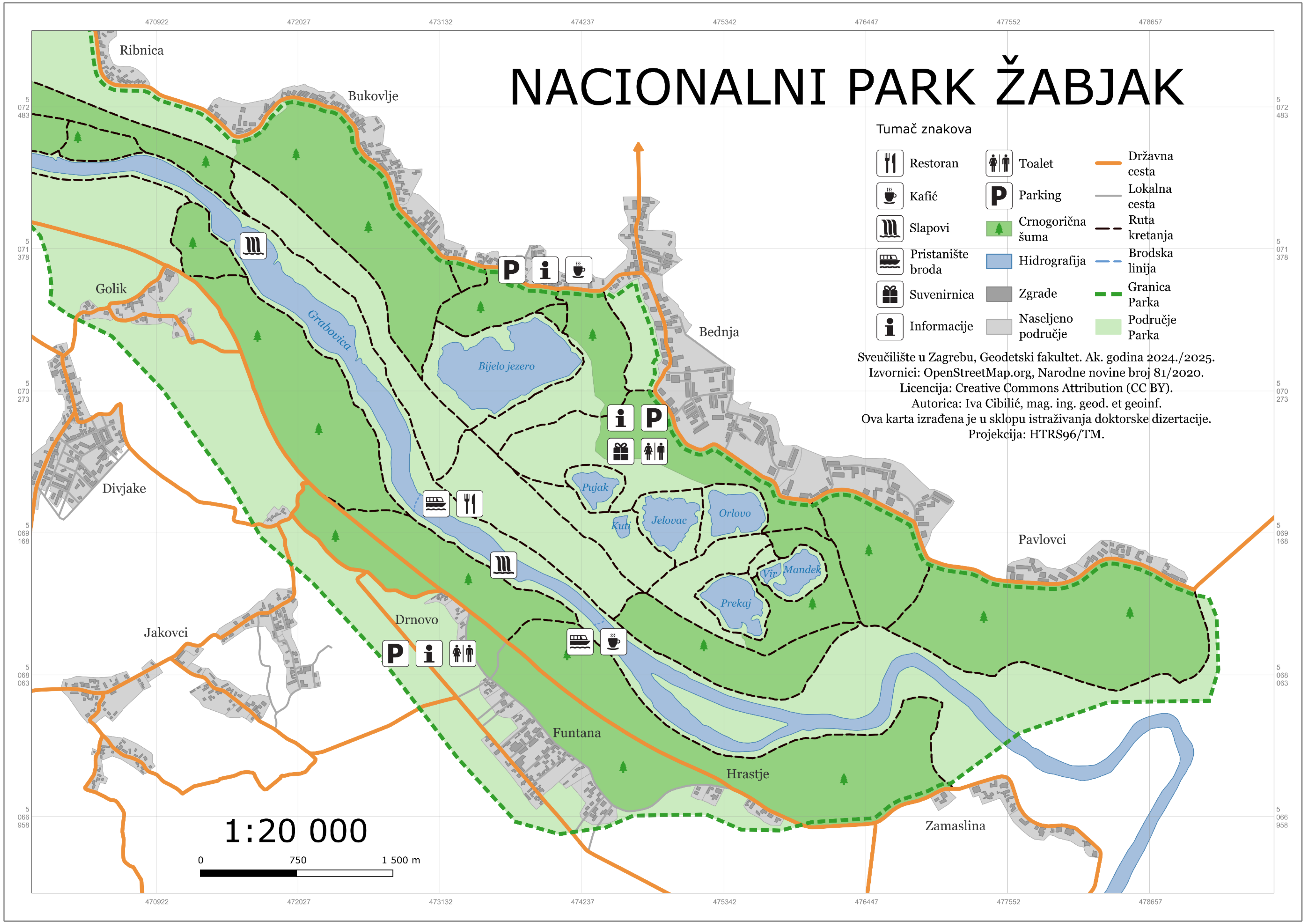
The table below summarises the requirements that guided stimulus design and the specific implementation choices made to meet them.

ID	Requirement	Source	Implementation in this thesis
1	Implement the AM concept through information layering.	Phase 2 inputs; cartographic rationale.	The AM was defined as two layers: (1) a printed base map layer and (2) a virtual augmentation layer. POIs were assigned to one of the two layers based on Phase 2 user inputs.
2	Reduce generalization on the printed map in dense POI areas.	Cartographic readability constraints; implications from map clutter in dense areas.	Selected POIs were moved from the printed layer to the virtual augmentation layer, reducing overlap and crowding on the paper map.
3	Keep task-relevant content at a manageable level to avoid unnecessary clutter and visual search effort.	Visual clutter / visual search literature; usability testing practicality; perception principles.	The amount of task-relevant POI content was intentionally limited to support legibility and reduce clutter-related visual search effort.
4	Use a standardised pictogram set.	Phase 1 map; Phase 2 inputs; national guidelines.	The standardised pictograms were used consistently across both conditions.
5	Avoid prior familiarity with real locations and allow controlled manipulation of map content.	Study control requirement; risk of participants knowing real parks.	Two fictional map areas were created, allowing controlled content design aligned with Phase 2 inputs while reducing familiarity effects.
6	Ensure the fictional areas remain plausible and comparable to the Croatian national-park tourism context.	Ecological validity and comparability.	The fictional environments were designed with national-park-like features (e.g., lakes, rivers, waterfalls) and comparable scale and overall visual complexity.
7	Assess AM usability against a familiar benchmark condition.	Study rationale; comparative approach in prior work (e.g., Herman et al., 2018).	Two comparable conditions were prepared: a traditional analogue map as the benchmark and an AM prototype as the augmented condition.
8	Maintain a controlled comparison so that performance differences reflect just the medium concept.	Experimental control logic for comparative usability evaluation.	Key map properties were kept consistent across conditions. The primary differences were the medium and the distribution of POIs across layers.
9	Use a within-subject design to reduce individual differences and improve statistical power.	Usability study design guidance (e.g., Lazar et al.).	Each participant completed tasks using both conditions (analogue and AM).
10	Reduce learning, order, and carryover effects associated with within-subject designs.	Within-subject validity threat; usability testing guidance (e.g., Lazar et al.).	The order of conditions was counterbalanced, and task sets were designed to be equivalent in structure and difficulty.
11	Keep augmentation vision-only to avoid	AR guidance on multimodal augmentation and added design complexity (e.g., Endsley et al.).	The AM prototype used visual augmentation only, without auditory or haptic cues.

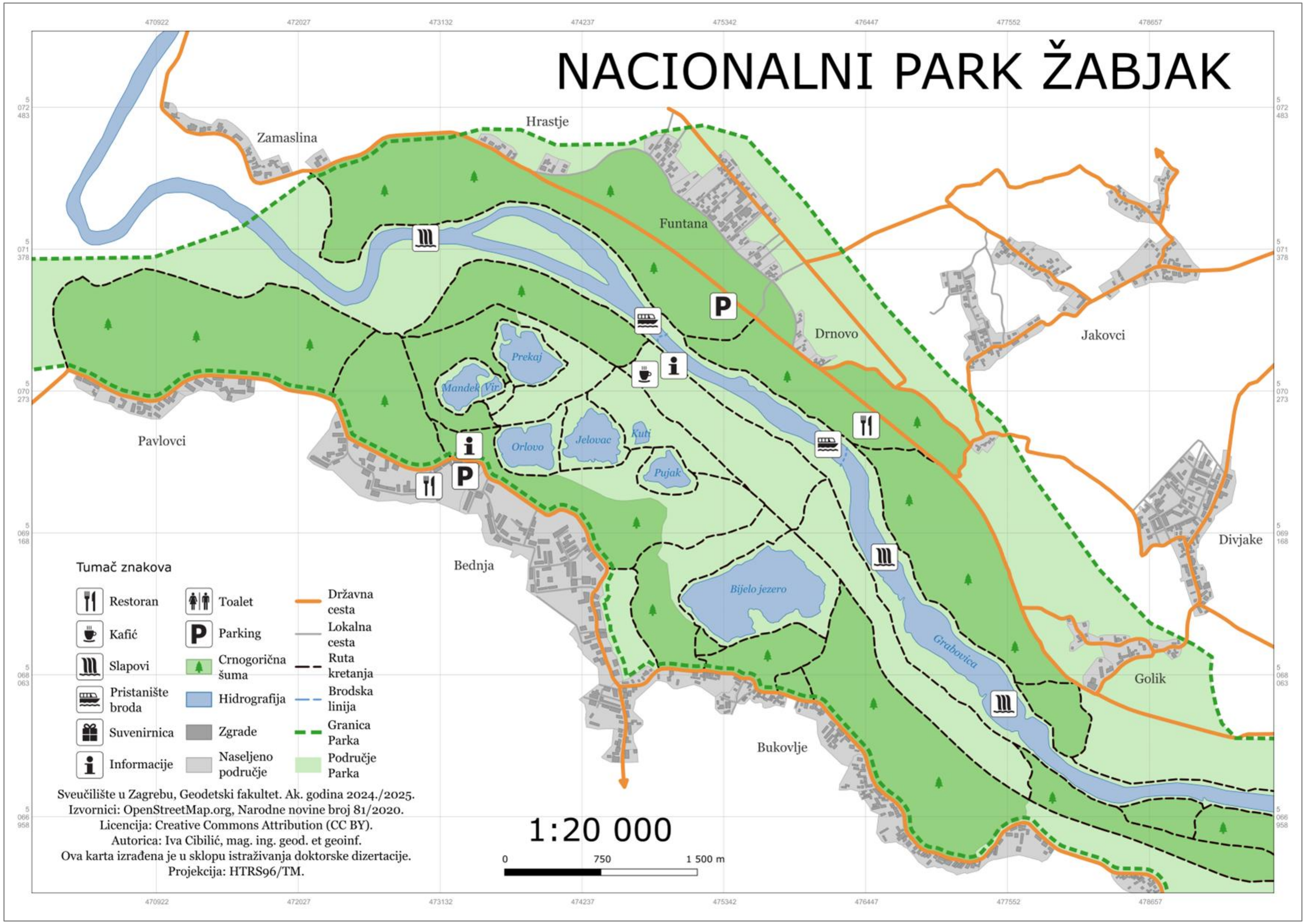
	introducing additional sensory confounds.		
12	Keep the visual form of AR content simple, so perceptual effects are not driven by 3D or animations.	Controlled comparison logic; AR usability considerations.	The augmentation consisted of static 2D pictogram sprites, avoiding elements such as 3D objects or dynamic effects.
13	Keep the interaction scope limited to visualisation.	Experimental control rationale (avoid introducing additional interface functionality).	The AM was implemented as a non-interactive visual overlay.
14	Reflect realistic tourist use by implementing the AM on a handheld device.	Handheld/mobile use in tourism; AR context (e.g., Livingston et al.).	The AM was designed for use on a handheld mobile device.
15	Use a tracking approach that supports stable alignment and is suitable for rapid prototyping.	Formative prototyping constraints; technical feasibility; AR tracking literature.	A marker-based prototype was implemented using the printed map as the visual target.
16	Support legibility and stable use in realistic conditions.	AR sensitivity to viewing distance/angle/lighting; wall-map/poster context (e.g., Grubert et al., 2014).	Maps were printed in A2 format and displayed as wall maps.
17	Avoid performance constraints by limiting the number of virtual elements.	Mobile AR limitations (e.g., Labrie and Cheng, 2020).	The number of simultaneously displayed virtual objects was kept limited to support stable performance and tracking.
18	Complement academic AR heuristics with relevant platform design guidance.	Platform/XR design guidance as practical recommendations.	Platform design guidance was reviewed and applied where relevant.
19	Ensure the workflow is transparent and reproducible.	Scientific transparency; replicability.	The analogue maps were produced in QGIS and exported as print-ready outputs and a marker image; the AM prototype was implemented in Unity (AR Foundation); documented and shared via GitHub.
20	Confirm that the stimuli are ready for evaluation before expert and user testing.	Prototyping good practice.	Internal checks confirmed: (1) print legibility, (2) cross-condition consistency, (3) stable marker detection under typical lighting, and (4) visually acceptable overlay alignment.
21	Follow formative UCD logic.	Formative UCD cycle; cost–accuracy considerations in iterative evaluation (e.g., Nielsen; John and Marks).	Version 1 stimuli were used in Phase 4 expert review and then refined for Phase 5 user testing, while preserving the controlled-comparison parameters.

C2. Map stimuli – Version 1 (used in Phase 4 expert review)

C2.1: Analogue stimulus (V1). Reproduced at reduced size for reference; not to scale.



C2.2: Augmented base map for tracking (V1). Reproduced at reduced size for reference; not to scale.



C2.3: Augmented map overlay view (V1). Reproduced at reduced size for reference; not to scale.

Appendix D – Phase 4: Expert cartographic review

D1. Expert test plan / evaluation sheet

Materials are provided in Croatian, as the expert evaluation was conducted in Croatian.

VRIJEME I LOKACIJA:

Geodetski fakultet, Kačićeva 26, 10000 Zagreb, soba 133, 1. kat. Istraživanje će se provoditi tijekom ljetnog semestra ak. god. 2024./2025.

SVRHA ISTRAŽIVANJA:

Ovim istraživanjem ispituje se upotrebljivost turističkih karata u proširenoj stvarnosti kroz stručnu evaluaciju kartografskih elemenata i interaktivnosti. Stručnjaci će analizirati kvalitetu kartografskog dizajna, jasnoću prikazanih informacija te potencijalna kognitivna opterećenja korisnika pri korištenju analogne i proširene karte. Stručna evaluacija pružit će smjernice za poboljšanje vizualne hijerarhije, kartografskih znakova i opće upotrebljivosti kako bi turističke karte bile preciznije, intuitivnije i prilagođene potrebama krajnjih korisnika.

CILJEVI ISTRAŽIVANJA:

Cilj stručne evaluacije je ispitati upotrebljivost tradicionalne i proširene karte kroz analizu kartografskih elemenata, vizualne jasnoće, kognitivnog opterećenja i interakcije korisnika s prikazanim informacijama. Stručnjaci će procijeniti koliko su karte učinkovite u prijenosu informacija te identificirati potencijalne probleme u njihovom dizajnu.

Kroz ovo istraživanje nastojat će se odgovoriti na sljedeća pitanja:

- Jesu li kartografski znakovi intuitivni i prepoznatljivi? Postoji li nejasnoća u vizualnoj komunikaciji informacija?
- Jesu li ključni elementi karata jasno istaknuti i lako uočljivi?
- Odgovaraju li boje, oznake i znakovi očekivanjima stručnjaka i općeprihvaćenim kartografskim standardima?
- Postoje li elementi na kartama koji su vizualno preopterećeni ili zbunjujući? Može li korisnik brzo obraditi informacije bez preopterećenja?
- Omogućavaju li karte brzo i točno pronalaženje informacija?
- Jesu li prošireni elementi jednostavni za upotrebu i razumijevanje? Pruža li proširena karta dodanu vrijednost u orijentaciji i snalaženju u prostoru?
- Kako bi stručnjaci poboljšali dizajn karti kako bi bile učinkovitije za krajnje korisnike?

Ova evaluacija omogućit će dubinsku analizu kartografskih i interaktivnih aspekata testiranih karata, s ciljem stvaranja preporuka za unaprjeđenje dizajna i bolje prilagodbe korisničkim potrebama.

SUDIONICI:

Za potrebe istraživanja planirano je angažirati pet stručnjaka iz područja kartografije, s iskustvom u dizajnu i analizi kartografskih prikaza. Ciljana skupina obuhvaća sveučilišne profesore i iskusne kartografe koji mogu pružiti dubinske povratne informacije o vizualnoj i funkcionalnoj učinkovitosti tradicionalne i proširene karte. U istraživanju je sudjelovalo sedam stručnjaka.

Sudionici će biti izravno pozvani putem akademskih i profesionalnih kontakata, a istraživanje će se provesti u kontroliranim uvjetima u unaprijed dogovorenom terminu. Kako bi se osiguralo strukturirano prikupljanje podataka, evaluacija će biti provedena uz korištenje unaprijed definiranih kriterija i scenarija koji pokrivaju heurističku analizu, kognitivni hod i pregled korisničkih zadataka.

Sudjelovanje stručnjaka omogućit će dobivanje dubinskih i kvalitetnih povratnih informacija koje će pridonijeti poboljšanju dizajna turističkih karata.

OPREMA I SNIMANJE PODATAKA:

- Analogni kartografski prikazi u A2 formatu namijenjeni za gledanje na zidu.
- Tablet za prikaz virtualnih elemenata proširenih turističkih karata.
- Kamera i mikrofon za snimanje ponašanja sudionika i verbalnih komentara.
- Prijenosno računalo i bilježnica za bilježenje opažanja i vođenje sesije.
- Obrazac suglasnosti za sudjelovanje u istraživanju i plan tijeka istraživanja.

TIJEK ISPITIVANJA:

Analogne karte bit će prikazane istovremeno, postavljene jedna uz drugu, kako bi stručnjaci mogli izravno usporediti rješenja; za proširenu kartu virtualni sloj bit će prikazan putem tableta. Ispitivanje će se odviti u kontroliranom okruženju u laboratorijskim uvjetima primjenom protokola razmišljanja naglas. Istraživač postavlja pitanja sudionicima i bilježi odgovore. Sudionici će sudjelovati u 60-minutnoj sesiji u sljedećem formatu:

5 minuta	Uvod i informirani pristanak
30-40 minuta	Upoznavanje sa sadržajem karte Evaluacija karti
10 minuta	Pregled i analiza zadataka korisnika
5 minuta	Završni komentari i povratne informacije

<u>ZADACI</u>:

1. Upotrebljivost

- Jesu li karte lako razumljive na prvi pogled?
- Pružaju li karte dovoljno informacija za orijentaciju korisnika i pronalazak objekata?
- Mogu li korisnici intuitivno locirati ključne točke interesa?
- Je li interakcija s virtualnim elementima glatka i razumljiva?
- Jesu li znakovi, boje i ostali elementi karte korišteni dosljedno na karti?
- Jesu li objekti na karti pravilno naglašeni?
- Kako biste ocijenili jednostavnost korištenja i zadovoljstvo svakom kartom?

2. Kartografska načela

- Je li kartografski znakovi (piktogrami) jasno prikazuju ono što bi trebali predstavljati?
- Jesu li znakovi dovoljno veliki da budu prepoznatljivi, ali ne pretrpavaju kartu?
- Razlikuju li se jasno različiti kartografski elementi (npr. ceste, staze, vodene površine)?
- Jesu li oznake pravilno postavljene kako bi se izbjeglo preklapanje i zbunjenost?
- Je li mjerilo karte prikladno za namjenu?
- Odgovaraju li udaljenosti i raspored kartografskih znakova stvarnosti?
- Je li orijentacija karte intuitivna (sjever prema gore)?

3. Kognitivno opterećenje i obrada informacija

- Predstavlja li karta previše ili premalo informacija odjednom?
- Postoje li elementi koji su zbunjujući ili ometajući?
- Mogu li korisnici brzo pronaći ono što im treba, ili se teško snalaze u informacijama?
- Mora li korisnik zapamtiti previše informacija nakon što skrene pogled?
- Je li jednostavno prebacivati se između virtualnih i tiskanih elemenata (ako je potrebno)?
- Može li korisnik samostalno upravljati virtualnim sadržajem ili se osjeća prisiljenim na određeni način interakcije?

Za svaki identificirani problem istraživač bilježi: (a) opis problema, (b) zašto je važan, (c) prijedlog poboljšanja, i (d) na koju kartu se spomenuti problem odnosi.

SPECIFIKACIJE KORIŠTENIH UREĐAJA:

TABLET

Specifikacija	*Detalji*
Model uređaja	Samsung Galaxy Tab S7 FE (SM-T733)
Operativni sustav	Android 14 (One UI 6)
Veličina zaslona i rezolucija	12,4 inča, 2560 × 1600 piksela (TFT LCD)
Procesor	Qualcomm Snapdragon 778G
RAM	6 GB
Pohrana	128 GB
Trajanje baterije	10.090 mAh, do 13 sati reprodukcije videozapisa
Zaslon na dodir	Kapacitivni, podržava S Pen
Povezivost	Wi-Fi 5 (802.11ac), Bluetooth 5.2
Kamera	Prednja 5 MP, stražnja 8 MP (automatski fokus)
Priključci	USB-C (3.2 Gen 1, nema 3.5 mm priključak za slušalice)

KAMERA I MIKROFON

Specifikacija	Detalji
Model uređaja	Imilab Webcam CMSXJ22A
Rezolucija	1080p Full HD (1920 × 1080 piksela)
Senzor	2 MP CMOS senzor
Kut gledanja	85° širokokutni objektiv
Fokus	Automatski fokus (AF)
Mikrofon	Ugrađeni dvostruki mikrofon s redukcijom šuma
Povezivost	USB-A
Kompatibilnost	Windows, macOS, Android (ovisno o aplikaciji)

POZIV NA SUDJELOVANJE U ISTRAŽIVANJU:

Predmet: Poziv na sudjelovanje u stručnoj evaluaciji karata

Poštovane kolegice i kolege,

u sklopu svog istraživanja provodim evaluaciju upotrebljivosti tradicionalne analogne karte i proširene karte (eng. *AR map*) s ciljem ispitivanja njihove učinkovitosti.

Budući da ste upoznati s temom mojeg istraživanja, bilo bi mi iznimno korisno kada biste sudjelovali u stručnoj procjeni kreiranih kartografskih prikaza. Evaluacija traje otprilike 45 minuta i provodi se uživo u mojem uredu u Kačićevoj 26.

Vaše stručno mišljenje bilo bi od velike vrijednosti za daljnju analizu i interpretaciju rezultata. Ako ste zainteresirani, molim Vas da mi javite kako bismo dogovorili termin.

Unaprijed zahvaljujem na izdvojenom vremenu i podršci.

FOTOGRAFIJE POSTAVLJENOG ISTRAŽIVANJA:

Dvije karte bile su postavljene jedna uz drugu kako bi se osigurala bolja usporedivost.

Ispitivanje je bilo video i audio snimano mobilnim telefonom radi bilježenja svih pokazivanja po ploči, a računalna kamera postavljena na vrh ploče snimala je izraze lica stručnjaka.

OSOBNA SUGLASNOST ZA SUDJELOVANJE U ISTRAŽIVANJU

Tražimo Vašu suglasnost za sudjelovanje u istraživanju doktorskog rada „Razvoj korisnički usmjerene metodologije upotrebljivosti proširenih karata zasnovane na kartografskoj komunikaciji turističkih karata" Geodetskog fakulteta Sveučilišta u Zagrebu. Molimo vas da pročitate navedene informacije prije nego se odlučite dati ili ne dati svoj pristanak.

Voditeljica istraživanja: Iva Cibilić, mag. ing. geod. et geoinf., icibilic@geof.hr

Mentorica doktorskog rada: izv. prof. dr. sc. Vesna Poslončec-Petrić, vesna.posloncec@geof.hr

Svrha istraživanja: Unaprijediti razumijevanje korisničkog iskustva s proširenim turističkim kartama kroz analizu njihove upotrebljivosti. Dobiveni uvidi poslužit će za razvoj metodologije koja će pomoći u dizajniranju učinkovitijih i korisnicima prilagođenijih kartografskih rješenja.

Postupak istraživanja: U ovom dijelu istraživanja želimo dobiti dubinski uvid u korisničku percepciju proširenih karata (karta u proširenoj stvarnosti) korištenjem metode razmišljanja naglas. Ispitivanje će se provoditi uživo, a voditi će ih istraživači s Geodetskog fakulteta. Očekivano vrijeme trajanja svake sesije je do 60 minuta. Ako pristanete sudjelovati, postaviti ćemo vam neka pitanja o snalaženju na analognim i proširenim kartama. Također je predviđena upotreba tableta. Na kraju je potrebno ispuniti kratki upitnik o zadovoljstvu.

Samu sesiju nam je važno audio i video snimati kako bi se istraživačima omogućilo da kasnije analiziraju rečeno. Također će se voditi pisane bilješke zbog lakšeg praćenja reakcija ispitanika. Svi prikupljeni materijali obrađuju se u skladu sa Općom uredbom o zaštiti osobnih podataka (EU) 2016/679, (GDPR) i Zakonom o provedbi Opće uredbe o zaštiti osobnih podataka NN 42/2018.

Nakon provedene analize, prikupljeni materijali će biti izbrisani nakon 5 godina, a do tada brižljivo čuvani bez ikakvih identifikacijskih oznaka. Prilikom objave rezultata istraživanja postoji mogućnost da anonimni komentari i iskustva budu uključeni. Ako se informacije iz istraživanja budu koristile u bilo koju svrhu, neće se otkrivati nikakve pojedinosti koje bi omogućile trećim stranama da identificiraju ispitanike, niti će se te informacije koristiti na način koji bi im mogao naštetiti.

Sudjelovanje i odustajanje: Sudjelovanje u istraživanju je dobrovoljno. Ispitanici nisu dužni odgovoriti na pitanja na koja ne žele odgovarati. Ispitanici neće morati raspravljati o pitanjima o kojima ne žele. Svi sudionici slobodni su prekinuti sudjelovanje i odustati od istraživanja u bilo kojem trenutku bez posljedica i obrazloženja.

Svojim potpisom u nastavku potvrđujete da ste razumjeli svrhu istraživanja, te ujedno njime dajete informirani pristanak za sudjelovanje u istraživanju.

Pročitao/la sam i razumio/razumjela ovaj informirani pristanak te pristajem sudjelovati u ovom istraživanju.

Ime:

Datum: Potpis:

SKRIPTA ZA TESTIRANJE UPOTREBLJIVOSTI PROŠIRENIH TURISTIČKIH KARATA

1. Uvod i informirani pristanak (5 min)

Hvala vam što sudjelujete u ovoj stručnoj evaluaciji. Cilj ovog testiranja je procijeniti dvije karte s obzirom na upotrebljivost, kartografski dizajn i kognitivno opterećenje. Vaši će komentari pomoći poboljšati karte prije testiranja s korisnicima. Tijek sesije će se odvijati kako slijedi:

- Prvo ćete procijeniti karte prema ključnim kriterijima upotrebljivosti i kartografskim principima.
- Zatim ćete pregledati i komentirati korisničke zadatke.
- Na kraju, imat ćemo kratku raspravu o vašim općim dojmovima i preporukama.

Koristit ćemo metodu 'razmišljanja naglas', što znači da verbalizirate sve što primjećujete i razmišljate dok analizirate karte. Nema točnih ili netočnih odgovora—zanima nas vaš stručni pogled. S vašim dopuštenjem, snimit ću ovu sesiju kako bih kasnije mogla detaljno analizirati vaše komentare. Slažete li se s time? Ako se slažete, molim vas da pročitate i potpišete ovaj dokument koji objašnjava svrhu istraživanja, vaša prava i način na koji će se koristiti prikupljeni podaci. Ako imate bilo kakvih pitanja, slobodno pitajte.

2. Evaluacija karti (20 min)

„Sada ću vam dati malo vremena da samostalno pregledate karte. Možete koristiti priloženi popis kriterija kao vodič i zabilježite sva opažanja."

B) Rasprava i komentari

„Razgovarajmo sada o vašim opažanjima sljedećih aspekata:

Upotrebljivost (Efikasnost, Učinkovitost, Zadovoljstvo)

- Jasnoća informacija – Jesu li karte lako razumljive na prvi pogled?
- Fleksibilnost i učinkovitost korištenja – Pružaju li obje karte dovoljno informacija za orijentaciju korisnika i pronalazak objekata?
- Jednostavnost navigacije – Mogu li korisnici intuitivno locirati ključne točke interesa (POI)?
- Interakcija (za AR kartu) – Je li interakcija s virtualnim elementima glatka i razumljiva?
- Dosljednost – Jesu li znakovi, boje i ostali elementi karte korišteni dosljedno na karti?
- Vizualna hijerarhija – Jesu li objekti na karti pravilno naglašeni?
- Opće korisničko iskustvo – Kako biste ocijenili jednostavnost korištenja i zadovoljstvo svakom kartom?

Kartografska načela (Simbolizacija i čitljivost; Prostorna reprezentacija i mjerilo)

- Intuitivnost znakova – Je li kartografski znakovi (piktogrami) jasno prikazuju ono što bi trebali predstavljati?
- Veličina simbola i čitljivost – Jesu li znakovi dovoljno veliki da budu prepoznatljivi, ali ne pretrpavaju kartu?
- Kontrast i diferencijacija – Razlikuju li se jasno različiti kartografski elementi (npr. ceste, staze, vodene površine)?
- Pozicioniranje oznaka – Jesu li oznake pravilno postavljene kako bi se izbjeglo preklapanje i zbunjenost?
- Prikladna razina detalja – Je li mjerilo karte prikladno za namjenu?
- Točnost prostornih odnosa – Odgovaraju li udaljenosti i raspored kartografskih znakova stvarnosti?
- Orijentacija i usmjerenost – Je li orijentacija karte intuitivna (sjever prema gore)?

Kognitivno opterećenje i obrada informacija

- Količina informacija – Predstavlja li karta previše ili premalo informacija odjednom?
- Pretrpanost i preopterećenje – Postoje li elementi koji su zbunjujući ili ometajući?
- Efikasnost skeniranja – Mogu li korisnici brzo pronaći ono što im treba, ili se teško snalaze u informacijama?
- Opterećenje memorije (AR karta) – Mora li korisnik zapamtiti previše informacija nakon što skrene pogled?
- Prebacivanje između prikaza – Je li jednostavno prebacivati se između virtualnih i tiskanih elemenata (ako je potrebno)?
- Korisnička kontrola i sloboda (AR karta) – Može li korisnik samostalno upravljati virtualnim sadržajem ili se osjeća prisiljenim na određeni način interakcije?

C) Usporedba i zaključci

„Koja vam se od dviju karata čini korisnijom i intuitivnijom za korisnike? Koje su glavne prednosti i nedostaci svake?“

3. Pregled i analiza zadataka (10 min)

„Hvala vam! Sada ćemo pregledati zadatke koje će korisnici rješavati tijekom testiranja.

- Jesu li zadaci realni i relevantni za način na koji korisnici koriste turističke karte?
- Jesu li zadaci prikladno teški, ili bi ih trebalo pojednostaviti/prilagoditi?
- Hoće li ovi zadaci jasno pokazati razlike u upotrebljivosti između analogne i AR karte?

4. Završni komentari i povratne informacije (5 min)

„Prije nego što završimo, imate li još neke komentare ili prijedloge za poboljšanje karata?

- Postoje li ključni problemi s upotrebljivošću koji bi trebali biti riješeni prije testiranja s korisnicima?
- Smatrate li da proširena karta nudi bolje ili lošije iskustvo od analogne karte?
- Imate li još neki prijedlog za poboljšanje?

Hvala vam na vašem vremenu i stručnim povratnim informacijama! Vaši komentari bit će izuzetno vrijedni za daljnje prilagodbe prije korisničkog testiranja.“

D2. Expert comments and refinement log (table)

ID	Issue / recommendation	Change implemented in final stimuli	Component	Experts mentioning
1	Add a north indicator (north arrow).	Yes – north arrow added.	Both	7/7
2	Add a note on the printed AR base map indicating that additional AR content exists.	Yes –note added.	AM (printed AR base map)	7/7
3	Move virtual-only symbols to a fixed on-screen virtual legend (do not list them in the printed legend).	Yes – fixed virtual legend implemented.	AM (AR overlay)	7/7
4	Refine direction arrows so they indicate only the main movement directions; add direction labels where appropriate.	Yes – arrow logic/placement harmonised.	Both	6/7
5	Add road contours to improve road legibility.	Yes – road outlines harmonised.	Both	6/7
6	Correct the position of the lake name (Kuti).	Yes – corrected.	Both	5/7
7	Harmonise the boat line symbol between the map and the legend.	Yes – boat line matched in map and legend.	Both	5/7
8	Replace the toilet pictogram with a viewpoint pictogram.	Yes – toilet replaced by viewpoint.	Both	5/7
9	Show the full park extent (entire protected area) within the map frame.	Yes – full park extent shown.	Both	4/7
10	Differentiate typography between the map field and marginal content (consistent font rules).	Yes – font differentiated.	Both	4/7
11	Reorder legend entries to match map-reading logic and symbol hierarchy.	Yes – legend order refined.	Both	4/7
12	Remove overlaps between pictograms and background layers.	Yes – overlaps resolved.	Both	4/7
13	Clarify clustered symbols using a grouping treatment (e.g., clear boundary/outline).	Yes – clusters grouped with boundary.	Both	4/7
14	Reduce spacing within symbol clusters so grouped POIs read as one set.	Yes – cluster spacing reduced.	Both	4/7
15	Add missing buildings/objects where pictograms imply a structure (e.g., souvenir shop, café).	Yes – missing building objects added where needed.	Both	4/7
16	Implement richer AR interaction (e.g., toggles/layers/object selection).	No – out of scope to preserve stimulus comparability.	AM (AR overlay)	4/7
17	Use different map titles for the two stimuli.	Yes – titles differentiated.	Both	3/7
18	Add a “You are here” marker (if a fixed user position is defined).	No – user position not defined in controlled stimulus.	Both	3/7
19	Add missing contextual labels for key places (e.g., café name, waterfall name).	No – not necessary.	Both	3/7
20	Increase settlement label size and emphasis (e.g., larger and/or bold).	Yes – settlement labels enlarged.	Both	3/7
21	Reduce the font size of the scale text.	Yes – scale text reduced.	Both	3/7
22	Rename the boat route/line label for clarity.	No – not necessary.	Both	3/7
23	Remove the numeric scale (keep one scale representation).	Yes – numeric scale removed.	Both	3/7
24	Extend the linear scale with additional units/ticks (more detail).	Yes – linear scale extended.	Both	3/7
25	Reposition symbols near Drnovo for clearer association.	Yes – symbols adjusted.	AM (printed AR base map)	3/7

26	Improve AR stability (reduce symbol drift/movement in the AR overlay).	Yes – tracking marker adjusted to improve stability.	AM (tracking)	3/7
27	Proofread and improve the imprint descriptive text.	Yes – imprint text refined.	Both	2/7
28	Offset the boat dock symbol so it does not sit directly on the river line.	Yes – symbols adjusted.	Both	2/7
29	Clarify Phase 5 distance tasks: distance is measured along the path/trail (not straight-line).	Yes – task wording refined.	Phase 5 protocol	1/7
30	Reposition the southern café symbol so it clearly reads as on the riverbank.	Yes – symbols adjusted.	AM (printed AR base map)	1/7
31	Reposition POIs to strengthen association with the walking route (route-based spatial logic).	Yes – POIs adjusted to better align with trail.	AM (printed AR base map)	1/7
32	Clarify the park boundary symbol, it causes confusion.	Yes – park boundary symbol revised.	Both	1/7
33	Reposition settlement labels (Prelovci, Hrastje, Funtana) to avoid conflicts.	Yes – labels repositioned.	Both	1/7
34	Rename the route label to “walking trail/path” (clearer wording).	Yes – route label revised.	Both	1/7
35	Centre waterfall symbols on the river line for accurate placement.	Yes – waterfall centred.	Both	1/7
36	Reconsider whether the coordinate grid is necessary for typical tourist orientation.	No change.	Both	1/7
37	Add a topographic waterfall symbol where appropriate.	No – not necessary.	Both	1/7
38	Increase the legend title size to improve hierarchy.	No – not necessary.	Both	1/7
39	Correct the position of the river name.	No – not necessary.	Both	1/7
40	Clarify park access: indicate main entrances / entry points.	No – not necessary.	Both	1/7
41	Strengthen the distinction between the map field from marginal content by adding a map frame.	No – not necessary.	Both	1/7

Appendix E – Phase 5: User-based usability evaluation

E1. User test plan / evaluation sheet

Materials are provided in Croatian, as the usability evaluation was conducted in Croatian.

VRIJEME I LOKACIJA:

Geodetski fakultet, Kačićeva 26, 10000 Zagreb, soba 133, 1. kat. Istraživanje će se provoditi tijekom ljetnog semestra ak. god. 2024./2025.

SVRHA ISTRAŽIVANJA:

Istraživanjem se ispituje upotrebljivost turističkih karata u proširenoj stvarnosti s ciljem razumijevanja njihove učinkovitosti i efikasnosti u pružanju informacija korisnicima. Analizirat će se točnost i brzina odgovora korisnika prilikom interakcije s analognom i proširenom kartom te dobiti pokazatelji koji će pomoći u razvoju kartografskih rješenja prilagođenih potrebama korisnika. Provedbom ovog istraživanja očekuju se koristi u vidu unapređenja dizajna turističkih karata kako bi bile intuitivnije, informativnije i jednostavnije za korištenje.

CILJEVI ISTRAŽIVANJA:

1. Ispitivanje učinkovitosti kartografskih znakova - Analizirati koliko su korisnicima razumljivi kartografski znakovi u tradicionalnoj i proširenoj karti, mjerenjem točnosti i vremena prepoznavanja znakova.

Hipoteza: Očekuje se da će korisnici točnije i brže prepoznati kartografske znakove prikazane u proširenoj stvarnosti nego one tiskane na analognoj karti.

2. Ispitivanje navigacijske učinkovitosti – Analizirati koliko brzo i točno korisnici mogu pronaći određene točke interesa (POI) i informacije na karti.

Hipoteza: Pretpostavlja se da karta u proširenoj stvarnosti omogućuje brže i točnije snalaženje u prostoru u usporedbi s tradicionalnim kartama.

3. Procjena upotrebljivosti za specifične zadatke – Ispitati koliko je karta korisna za izvršavanje konkretnih zadataka (npr. pronalazak najkraće rute ili odabir atrakcije prema interesima).

Hipoteza: Pretpostavlja se da karta u proširenoj stvarnosti povećava uspješnost u rješavanju zadataka zahvaljujući boljoj vizualizaciji informacija.

4. Analiza korisničkog iskustva – Utvrditi kako korisnici doživljavaju kartu u smislu lakoće korištenja, vizualne privlačnosti i zadovoljstva.

Hipoteza: Očekuje se da će korisnici pokazati veće zadovoljstvo kartama u proširenoj stvarnosti nego tradicionalnim kartama.

5. Utjecaj prostornih sposobnosti na upotrebljivost karata - Analizirati kako individualne prostorne sposobnosti korisnika (mjereno SBSOD upitnikom) utječu na njihovu učinkovitost i točnost pri korištenju različitih vrsta karata.

Hipoteza: Korisnici s višim SBSOD rezultatima bit će uspješniji u navigaciji i rješavanju zadataka, neovisno o vrsti karte.

Pitanja na koja istraživanje nastoji odgovoriti:

- Jesu li kartografski znakovi razumljivi korisnicima i poboljšava li proširena karta njihovo prepoznavanje?
- Koliko su korisnici učinkoviti u pronalaženju traženih informacija i olakšava li proširena karta taj proces?
- Poboljšava li proširena karta navigacijsku učinkovitost i smanjuje li pogreške pri određivanju ruta?
- Je li proširena karta intuitivna i jednostavna za korištenje pri navigaciji i planiranju?
- Imaju li korisnici s boljim prostornim sposobnostima značajno bolje rezultate u korištenju obje vrste karata?
- Pokazuju li korisnici veće zadovoljstvo i percepciju upotrebljivosti proširene karte u odnosu na tradicionalnu kartu?

Ovi rezultati pomoći će u oblikovanju turističkih karata koje bolje odgovaraju potrebama korisnika i olakšavaju njihovu uporabu u stvarnom svijetu.

<u>SUDIONICI</u>:

Za potrebe istraživanja planirano je regrutirati ukupno 40 sudionika, ali sudjelovalo ih je 48. Svaki sudionik rješava zadatke na obje karte (analogna i proširena), a redoslijed prikaza karata je uravnotežen na način da približno polovica sudionika prvo rješava zadatke na analognoj karti pa na proširenoj karti, a druga polovica sudionika obrnutim redoslijedom. Ovaj pristup je primijenjen kako bi se dobile pouzdane metrike upotrebljivosti i osigurala dovoljna raznolikost rezultata. Ciljana skupina obuhvaća turiste koji posjećuju nacionalne parkove u Republici Hrvatskoj, s naglaskom na raznolike demografske karakteristike:

- Dob: 18 - 65 godina, kako bi se obuhvatila različita dobna skupina korisnika karata.
- Porijeklo: Sudionici će uključivati domaće turiste zbog lokacijskih ograničenja.

- Iskustvo: Sudionici s različitim razinama iskustva u korištenju karti – od povremenih korisnika do onih koji ih često koriste. Iskustvo u korištenju proširene stvarnosti također će se uzeti u obzir.
- U slučaju da tijekom istraživanja nastanu problemi sa slabovidnim sudionicima isti će biti isključeni iz daljnje obrade rezultata.

Sudionici će se regrutirati putem društvenih mreža i objavama na internetskim stranicama fakulteta. Istraživanje će se provesti u kontroliranim uvjetima, uz raspored sudionika koji osigurava vremenske razmake između sesija kako bi se omogućilo temeljito prikupljanje podataka i priprema za sljedeće sudionike. Ova raznolikost omogućit će uvid u upotrebljivost karti kod šireg kruga korisnika te će pridonijeti razvoju rješenja koja su prilagođena potrebama svih korisnika.

OPREMA I SNIMANJE PODATAKA:

- Analogni kartografski prikazi u A2 formatu namijenjeni za gledanje na zidu.
- Tablet za prikaz virtualnih elemenata proširenih turističkih karata.
- Štoperica za mjerenje vremena potrebnog za izvršenje zadataka.
- Kamera i mikrofon za snimanje ponašanja sudionika, verbalnih komentara i neverbalnih znakova tijekom istraživanja.
- Prijenosno računalo ili bilježnica za bilježenje opažanja, ručno bilježenje vremena i točnosti odgovora i vođenje sesije.
- Obrazac suglasnosti za sudjelovanje u istraživanju, plan tijeka istraživanja, SBSOD upitnik i upitnik o zadovoljstvu za prikupljanje povratnih informacija, kao i ocjena nakon zadatka.

TIJEK ISPITIVANJA:

Svaki sudionik izvršava sve zadatke na obje karte; redoslijed (analogna → proširena ili proširena → analogna) je uravnotežen između sudionika. Ispitivanje se provodi u kontroliranom laboratorijskom okruženju uz primjenu protokola razmišljanja naglas. Istraživač postavlja pitanja i zadatke sudionicima i prati njihovo ponašanje i bilježi odgovore. Sudionici će sudjelovati u 20-minutnoj sesiji u sljedećem formatu:

5 minuta	Uvod Kratki intervju (5-6 pitanja) Rješavanje SBSOD upitnika
10 minuta (2 x 5 min)	Upoznavanje sa sadržajem karte 5 zadataka po karti Sudionik ispunjava upitnik o zadovoljstvu nakon korištenja svake karte
5 minuta	Istraživač postavlja dodatna pitanja

ZADACI:

Slijedi popis tipova zadataka koji se provode u oba ispitana uvjeta. Za svaki tip zadatka navedena su dva pitanja: pitanje u gornjem retku odnosi se na analognu kartu, a pitanje u donjem retku na proširenu kartu. Konkretni objekti i lokacije se razlikuju između uvjeta radi smanjenja efekta pamćenja.

1 Razumijevanje kartografskih znakova (Lako – Razumijevanje)

- „Što ovaj znak predstavlja?“ (Suvenirnica)
- „Što ovaj znak predstavlja?“ (Vidikovac)

2 Pronalaženje POI-a (Lako – Pretraga)

- „Pronađite vidikovac koji je najbliži kafiću koji se nalazi u sjevernom dijelu parka.“
- „Pronađite suvenirnicu koja je najbliža restoranu u istočnom dijelu parka.“

3 Usporedba udaljenosti objekata (srednje – pretraga)

- „Je li kafiću u sjevernom dijelu parka bliži vidikovac ili suvenirnica?“
- „Je li restoranu u istočnom dijelu parka bliži vidikovac ili suvenirnica?“

4 Pronalaženje najbliže lokacije iz polazne točke (srednje – navigacija)*

* Napomena: *Udaljenost se odnosi na udaljenost po stazama, ne na zračnu udaljenost*.

- „Nalazite se na južnom parkiralištu. Gdje se nalazi najbliža suvenirnica?“
- „Nalazite se u zapadnom info centru. Gdje se nalazi najbliži vidikovac?“

5 Pronalaženje najkraćeg puta (teško – navigacija)

- „Pronađite najkraći put od restorana do vidikovca i opišite rutu.“
- „Pronađite najkraći put od kafića do suvenirnice i opišite rutu.“
- Dodatno pitanje (za obje karte): „Što je bliže restoranu/kafiću – vidikovac ili suvenirnica?“

Kombinacija objektivnih (npr. vrijeme zadatka, točnost) i subjektivnih podataka (npr. povratne informacije sudionika) osigurava sveobuhvatnu analizu upotrebljivosti i učinkovitosti AR turističkih karata.

KRITERIJI USPJEŠNOSTI I TOČNOSTI ZADATAKA:

Za svaki zadatak bilježi se uspješnost kao binarna mjera (1 = točno, 0 = netočno) prema unaprijed pripremljenom ključu točnih odgovora.

Odgovor na prvi zadatak (prepoznavanje značenja kartografskog znaka) smatra se točnim ako sudionik navede točan pojam koji znak predstavlja ili jasno prihvatljiv sinonim (npr. "vidikovac" = "mjesto za promatranje").

Kod zadataka pronalaska objekta (zadaci dva i tri) odgovor se smatra točnim ako sudionik nedvosmisleno identificira traženi objekt na karti (pokazivanjem na ispravan kartografski znak i/ili usmenim imenovanjem). Ako sudionik pokaže na pogrešan objekt ili ne može završiti zadatak bez pomoći, odgovor se bilježi kao netočan.

Odgovor na četvrti zadatak (pronalaženje najbliže lokacije iz polazne točke) smatra se točnim ako sudionik odabere opciju koja je najbliža prema unaprijed izračunatom ključu. Udaljenost je definirana kao udaljenost po stazama te se ta definicija usmeno naglašava pri postavljanju zadatka. Ako sudionik odabere drugu opciju ili ne može donijeti odluku, odgovor se bilježi kao netočan.

Odgovor na zadatak pronalaska najkraćeg puta smatra se točnim ako sudionik odabere rutu koja odgovara unaprijed određenoj najkraćoj ruti prema mreži staza. Ako sudionik odabere alternativnu rutu koja je usporediva po duljini (ekvivalentna) unaprijed određenoj najkraćoj ruti, odgovor se također može bilježiti kao točan (uz napomenu). Ako sudionik ne koristi stazu ili odabere dulju rutu, odgovor se bilježi kao netočan.

Vrijeme izvršavanja zadatka mjeri se štopericom i bilježi u sekundama. Mjerenje vremena započinje u trenutku kada istraživač završi čitanje zadatka. Mjerenje završava kada sudionik prvi put jasno signalizira konačan odgovor – pokazivanjem na odabrani objekt/rutu i/ili izgovaranjem odgovora. Ako sudionik nakon toga samostalno ispravi odgovor, za analizu vremena bilježi se vrijeme do konačnog odgovora.

SPECIFIKACIJE KORIŠTENIH UREĐAJA:

TABLET

Specifikacija	*Detalji*
Model uređaja	Samsung Galaxy Tab S7 FE (SM-T733)
Operativni sustav	Android 14 (One UI 6)
Veličina zaslona i rezolucija	12,4 inča, 2560 × 1600 piksela (TFT LCD)
Procesor	Qualcomm Snapdragon 778G
RAM	6 GB
Pohrana	128 GB
Trajanje baterije	10.090 mAh, do 13 sati reprodukcije videozapisa
Zaslon na dodir	Kapacitivni, podržava S Pen
Povezivost	Wi-Fi 5 (802.11ac), Bluetooth 5.2
Kamera	Prednja 5 MP, stražnja 8 MP (automatski fokus)
Priključči	USB-C (3.2 Gen 1, nema 3.5 mm priključak za slušalice)

KAMERA I MIKROFON

Specifikacija	Detalji
Model uređaja	Imilab Webcam CMSXJ22A
Rezolucija	1080p Full HD (1920 × 1080 piksela)
Senzor	2 MP CMOS senzor
Kut gledanja	85° širokokutni objektiv
Fokus	Automatski fokus (AF)
Mikrofon	Ugrađeni dvostruki mikrofon s redukcijom šuma
Povezivost	USB-A
Kompatibilnost	Windows, macOS, Android (ovisno o aplikaciji)

POZIV NA SUDJELOVANJE U ISTRAŽIVANJU:

a) Društvene mreže (Facebook, Linkedin, Instagram)

🎯 Sudjelujte u istraživanju i pomozite poboljšati turističke karte! 🎯

Pozdrav svima! 👋

Tražim volontere za sudjelovanje u kratkom korisničkom testiranju turističkih karata. Cilj istraživanja je bolje razumjeti kako ljudi čitaju i koriste karte te kako ih možemo poboljšati!

📍 Detalji:

☑ Trajanje: 25-30 minuta

☑ Lokacija: Geodetski fakultet (Kačićeva 26, Zagreb)

☑ Nisu potrebna posebna predznanja

☑ Zanimljivo, edukativno i korisno iskustvo!

Vaše sudjelovanje će pomoći u razvoju kvalitetnijih turističkih karti – a možda i otkrijete nešto novo o sebi kao kartografu! 🗺

Ako ste zainteresirani, slobodno mi se javite u inbox ili na icibilic@geof.hr. Također, ako poznajete nekoga tko bi mogao biti zainteresiran, podijelite ovu poruku! Hvala! 😊

b) Direktna komunikacija emailom

Predmet: Poziv za sudjelovanje u istraživanju o turističkim kartama

Poštovani,

Moje ime je Iva i provodim istraživanje u sklopu doktorskog rada na Geodetskom fakultetu Sveučilišta u Zagrebu. Istraživanje se bavi razumijevanjem načina na koji korisnici čitaju i koriste turističke karte te mogućnostima za njihovo poboljšanje.

U tu svrhu tražim volontere koji bi sudjelovali u kratkom korisničkom testiranju. Njihov doprinos bio bi iznimno vrijedan za istraživanje, a istovremeno bi im omogućio stjecanje korisnog iskustva. Predviđeno trajanje ispitivanja je do 30 minuta, a odvija se u prostorijama Geodetskog fakulteta (Kačićeva 26, Zagreb). Za sudjelovanje u istraživanju nisu potrebna posebna predznanja– samo iskreno mišljenje!

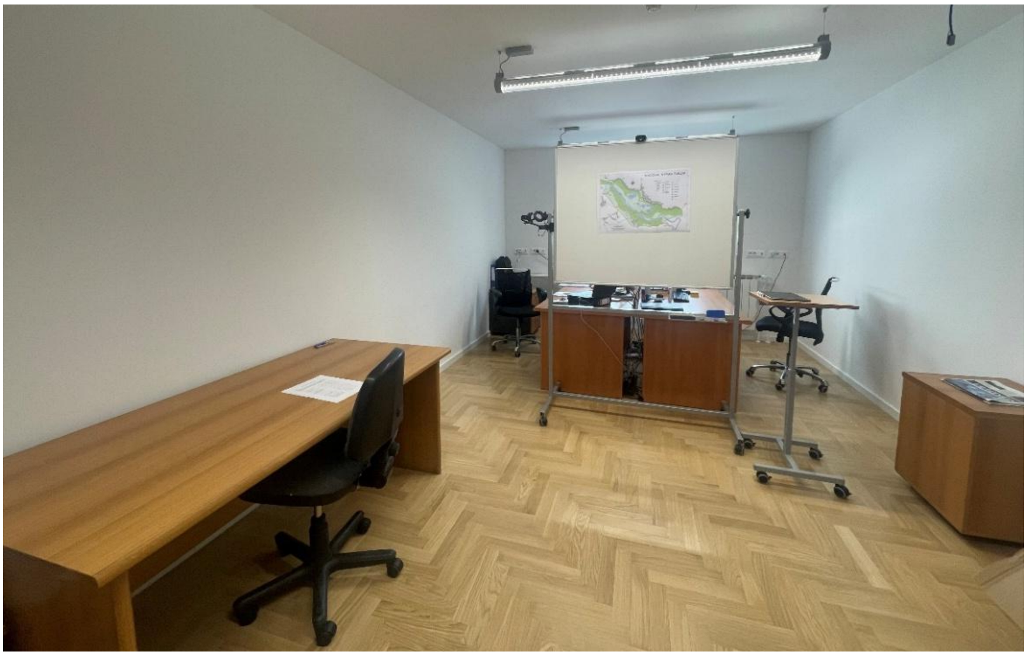
Bila bi vrlo zahvalna ako biste ovu informaciju mogli podijeliti putem mailing liste, oglasne ploče ili društvenih mreža.

Zainteresirani sudionici mogu se prijaviti ili dobiti više informacija slanjem e-maila na icibilic@geof.hr do 30.4.2025.

Hvala unaprijed na pomoći i podršci!

c) Letak kojim se pozivaju svi zainteresirani za sudjelovanje u istraživanju

FOTOGRAFIJE POSTAVLJENOG ISTRAŽIVANJA:



Za korisničko ispitivanje upotrebljivosti osiguran je stol radi lakše distribucije upitnika.

Korisničko ispitivanje upotrebljivosti također je snimano mobitelom i računalnom kamerom.

Svaka je karta evaluirana neovisno, po jedna karta na svakoj strani rotirajuće ploče, kako bi se tijek ispitivanja odvijao bez prekida.

OSOBNA SUGLASNOST ZA SUDJELOVANJE U ISTRAŽIVANJU

Tražimo Vašu suglasnost za sudjelovanje u istraživanju doktorskog rada „Razvoj korisnički usmjerene metodologije upotrebljivosti proširenih karata zasnovane na kartografskoj komunikaciji turističkih karata" Geodetskog fakulteta Sveučilišta u Zagrebu. Molimo vas da pročitate navedene informacije prije nego se odlučite dati ili ne dati svoj pristanak.

Voditeljica istraživanja: Iva Cibilić, mag. ing. geod. et geoinf., icibilic@geof.hr

Mentorica doktorskog rada: izv. prof. dr. sc. Vesna Poslončec-Petrić, vesna.posloncec@geof.hr

Svrha istraživanja: Unaprijediti razumijevanje korisničkog iskustva s proširenim turističkim kartama kroz analizu njihove upotrebljivosti. Dobiveni uvidi poslužit će za razvoj metodologije koja će pomoći u dizajniranju učinkovitijih i korisnicima prilagođenijih kartografskih rješenja.

Postupak istraživanja: U ovom dijelu istraživanja želimo dobiti dubinski uvid u korisničku percepciju proširenih karata (karta u proširenoj stvarnosti) korištenjem metode razmišljanja naglas. Ispitivanje će se provoditi uživo, a voditi će ih istraživači s Geodetskog fakulteta. Očekivano vrijeme trajanja svake sesije je do 60 minuta. Ako pristanete sudjelovati, postaviti ćemo vam neka pitanja o snalaženju na analognim i proširenim kartama. Također je predviđena upotreba tableta. Na kraju je potrebno ispuniti kratki upitnik o zadovoljstvu.

Samu sesiju nam je važno audio i video snimati kako bi se istraživačima omogućilo da kasnije analiziraju rečeno. Također će se voditi pisane bilješke zbog lakšeg praćenja reakcija ispitanika. Svi prikupljeni materijali obrađuju se u skladu sa Općom uredbom o zaštiti osobnih podataka (EU) 2016/679, (GDPR) i Zakonom o provedbi Opće uredbe o zaštiti osobnih podataka NN 42/2018.

Nakon provedene analize, prikupljeni materijali će biti izbrisani nakon 5 godina, a do tada brižljivo čuvani bez ikakvih identifikacijskih oznaka. Prilikom objave rezultata istraživanja postoji mogućnost da anonimni komentari i iskustva budu uključeni. Ako se informacije iz istraživanja budu koristile u bilo koju svrhu, neće se otkrivati nikakve pojedinosti koje bi omogućile trećim stranama da identificiraju ispitanike, niti će se te informacije koristiti na način koji bi im mogao naštetiti.

Sudjelovanje i odustajanje: Sudjelovanje u istraživanju je dobrovoljno. Ispitanici nisu dužni odgovoriti na pitanja na koja ne žele odgovarati. Ispitanici neće morati raspravljati o pitanjima o kojima ne žele. Svi sudionici slobodni su prekinuti sudjelovanje i odustati od istraživanja u bilo kojem trenutku bez posljedica i obrazloženja.

Svojim potpisom u nastavku potvrđujete da ste razumjeli svrhu istraživanja, te ujedno njime dajete informirani pristanak za sudjelovanje u istraživanju.

Pročitao/la sam i razumio/razumjela ovaj informirani pristanak te pristajem sudjelovati u ovom istraživanju.

Ime:

Datum: Potpis:

SKRIPTA ZA TESTIRANJE UPOTREBLJIVOSTI PROŠIRENIH TURISTIČKIH KARATA

5. Uvod i informirani pristanak (5 min)

„Dobar dan i hvala vam što sudjelujete u ovom istraživanju. Moje ime je Iva i provodim istraživanje o upotrebljivosti turističkih karata, s ciljem poboljšanja njihove razumljivosti i učinkovitosti.
Prvo ćemo proći kroz informirani pristanak. Ovaj dokument objašnjava svrhu istraživanja, vaša prava i način na koji će se koristiti prikupljeni podaci. Molim vas da ga pročitate i potpišete ako se slažete sa sudjelovanjem. Ako imate bilo kakvih pitanja, slobodno ih postavite.“
(Sudionik čita i potpisuje informirani pristanak.)

6. Uvodni intervju (5 min)

„Prije nego što krenemo s glavnim zadacima, postavit ću vam nekoliko kratkih pitanja o vašem iskustvu s kartama i tehnologijom. Samo kratko odgovorite—nema točnih ili netočnih odgovora. Ako ne želite odgovoriti na neko pitanje, slobodno mi recite."

- Koliko imate godina? (Otvoreni odgovor)
- Koliko često koristite karte za navigaciju? (1 – Rijetko, 5 – Vrlo često)
- Koliko ste upoznati s tehnologijom proširene stvarnosti (AR)? (1 – Uopće nisam upoznat/a, 5 – Vrlo dobro poznajem AR)
- Imate li oštećenje vida koje bi moglo utjecati na čitanje karata? (Da / Ne)
- Koliko često putujete? (1 – Rijetko, 5 – Vrlo često)
- Koliko ste nacionalnih parkova do sada posjetili? (Otvoreni odgovor)
- Kako biste ocijenili svoje navigacijske sposobnosti? (1 – Vrlo loše, 5 – Izvrsno)
- Koliko često koristite pametni telefon za navigaciju? (Rijetko / Ponekad / Često / Uvijek)
- Osjećate li nelagodu prilikom korištenja AR ili VR aplikacija? (Da / Ne / Nisam siguran/na)
- Kada se snalazite na nepoznatom mjestu, što najčešće koristite? (Papirnate karte / Digitalne karte na mobitelu / Pitam ljude za smjer)

(Sudionik odgovara na postavljena pitanja.)

7. Upitnik o osjećaju za orijentaciju (SBSOD) (5 min)

„Hvala vam! Sada slijedi kratki upitnik koji mjeri vaš osjećaj za orijentaciju i snalaženje u prostoru. Ovaj upitnik nema točnih ili netočnih odgovora – zanima nas vaše osobno iskustvo i dojam.“
(Sudionik ispunjava Santa Barbara Sense of Direction Scale - SBSOD.)

8. Rješavanje zadataka s prvom kartom (10 min)

„Sada ćemo prijeći na prvi dio zadataka. Na zidu ispred vas nalazi se prva karta. Vaš zadatak je pronaći i identificirati određene objekte ili rute na karti. Dok rješavate zadatke, molim vas da glasno izgovarate što radite i što razmišljate – ovo se zove *'think-aloud'* metoda i pomaže nam razumjeti vaše procese razmišljanja.“

(Sudionik rješava zadatke, istraživač bilježi vrijeme rješavanja i točnost odgovora.)

9. SUS upitnik za prvu kartu (5 min)

„Hvala vam! Sada vas molim da ispunite kratki upitnik o vašem iskustvu korištenja ove karte. Upitnik se sastoji od nekoliko tvrdnji o karti, a vi ćete ih ocijeniti na ljestvici od 1 do 5, gdje 1 znači da se potpuno ne slažete, a 5 da se potpuno slažete.“

(Sudionik ispunjava SUS upitnik za prvu kartu.)

10. Rješavanje zadataka s drugom kartom (10 min)

„Sada ćemo prijeći na drugi set zadataka s drugom kartom. Postupak je isti – molim vas da pokušate riješiti zadatke i glasno izgovarate svoje misli dok ih rješavate.“

(Sudionik rješava zadatke, istraživač bilježi vrijeme rješavanja i točnost odgovora.)

11. SUS upitnik za drugu kartu (5 min)

„Hvala vam! Još jednom vas molim da ispunite SUS upitnik, ali ovaj put za drugu kartu. Ocijenite svoje iskustvo korištenja ove karte na isti način kao i ranije.“

(Sudionik ispunjava SUS upitnik za drugu kartu.)

12. Završni komentari i povratne informacije (5 min)

„Odlično, završili smo s testiranjem! Sada bih volio/voljela čuti vaše dojmove.

- Kako biste opisali svoje iskustvo korištenja ovih karata?
- Je li neka karta bila intuitivnija ili lakša za korištenje?
- Jeste li naišli na poteškoće prilikom rješavanja zadataka?
- Imate li prijedloge kako bi se ove karte mogle poboljšati?“

(Sudionik dijeli svoje komentare, istraživač zapisuje ključne napomene.)

13. Zahvala i završetak

„Hvala vam puno na vašem vremenu i sudjelovanju! Vaši odgovori su izuzetno korisni za ovo istraživanje. Ako imate bilo kakvih pitanja ili vas zanima više o rezultatima istraživanja, slobodno me kontaktirajte. Želim vam ugodan dan!“

(Sudionik završava testiranje.)

SANTA BARBARA SKALA OSJEĆAJA ZA SMJER

Upute:

Sljedeće tvrdnje odnose se na vaše prostorne i navigacijske sposobnosti, preferencije i iskustva. Nakon svake tvrdnje, zaokružite broj koji označava razinu vašeg slaganja s tvrdnjom. Koristite ljestvicu od **1 do 5**, gdje:

1 U potpunosti se ne slažem	2 Ne slažem se	3 Neutralno	4 Slažem se	5 U potpunosti se slažem

Tvrdnje:

1. Vrlo sam dobar/ra u davanju uputa.	1	2	3	4	5
2. Često zaboravljam gdje sam ostavio/la stvari.	1	2	3	4	5
3. Vrlo dobro procjenjujem udaljenosti.	1	2	3	4	5
4. Imam dobar osjećaj za smjer.	1	2	3	4	5
5. Svoju okolinu obično zamišljam prema glavnim stranama svijeta (sjever, jug, istok, zapad).	1	2	3	4	5
6. Lako se izgubim u nepoznatom gradu.	1	2	3	4	5
7. Uživam u čitanju karata.	1	2	3	4	5
8. Teško razumijem upute za kretanje.	1	2	3	4	5
9. Vrlo sam dobar/ra u čitanju karata.	1	2	3	4	5
10. Ne pamtim dobro rute dok sam suvozač/ica u automobilu.	1	2	3	4	5
11. Ne volim davati upute za kretanje.	1	2	3	4	5
12. Nije mi važno znati gdje se točno nalazim.	1	2	3	4	5
13. Planiranje rute na dužim putovanjima obično prepuštam drugima.	1	2	3	4	5
14. Obično zapamtim novu rutu nakon što sam je prošao/la samo jednom.	1	2	3	4	5
15. Nemam baš dobru „mentalnu kartu“ svoje okoline.	1	2	3	4	5

UPITNIK O ZADOVOLJSTVU

Upute:

Molimo vas da procijenite koliko se slažete ili ne slažete s navedenim tvrdnjama u vezi s **kartom** koju ste upravo koristili.

Koristite ljestvicu od **1 do 5**, gdje:

1 U potpunosti se ne slažem	2 Ne slažem se	3 Neutralno	4 Slažem se	5 U potpunosti se slažem

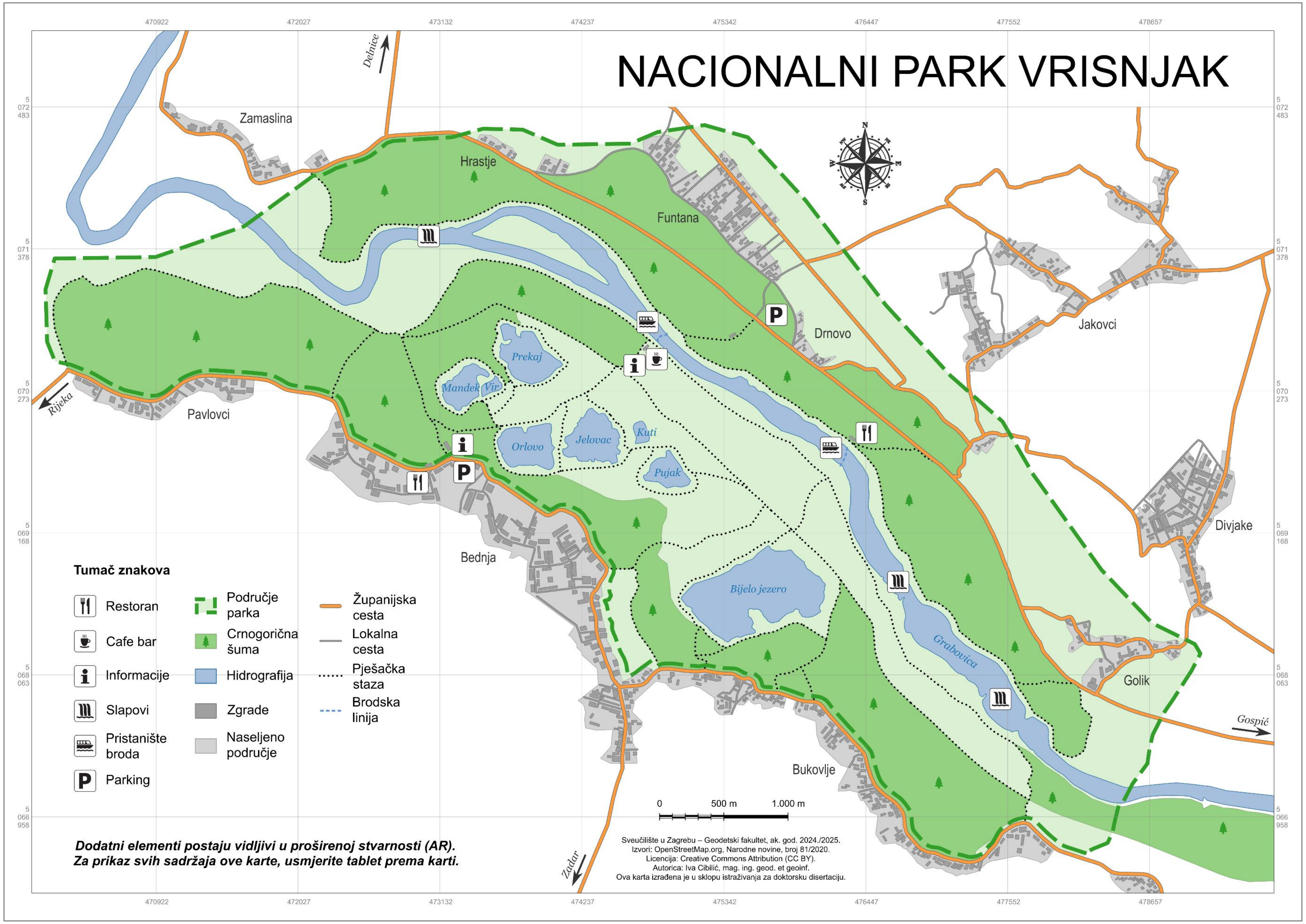
Tvrdnje:

1. Mislim da bi ovu kartu volio/la češće koristiti.	1	2	3	4	5
2. Smatram da je ova karta nepotrebno složena.	1	2	3	4	5
3. Mislim da je ova karta jednostavna za korištenje.	1	2	3	4	5
4. Mislim da mi je potrebna pomoć stručne osobe za korištenje ove karte.	1	2	3	4	5
5. Smatram da su mogućnosti karte dobro povezane.	1	2	3	4	5
6. Mislim da ova karta ima previše nedosljednosti.	1	2	3	4	5
7. Vjerujem da bi većina ljudi brzo naučila koristiti ovu kartu.	1	2	3	4	5
8. Ova karta mi je bila nespretna za korištenje.	1	2	3	4	5
9. Osjećao/la sam se samouvjereno dok sam koristio/la ovu kartu.	1	2	3	4	5
14. Prije korištenja ove karte potrebno je naučiti mnogo novih stvari.	1	2	3	4	5

E2. Map stimuli – Version 2 (used in Phase 5 user-based usability testing)

E2.1: Analogue stimulus (V2). Reproduced at reduced size for reference; not to scale.

E2.2: Augmented base map for tracking (V2). Reproduced at reduced size for reference; not to scale.



E2.3: Augmented map overlay view (V2). Reproduced at reduced size for reference; not to scale.

CURRICULUM VITAE