From Method of Loci to Digital Mnemonics: AI, AR, and the Future of Memory

by

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Abstract

In today's world, the sheer volume of information challenges our ability to remember effectively, prompting innovative approaches to cognitive support. This thesis explores how Artificial Intelligence (AI) and Augmented Reality (AR) can work together to enrich memory. Building on traditional methods such as the Method of Loci (Memory Palace Technique), the study uses the Research through Design (RtD) and Speculative Design approach to iteratively develop and experiment with prototypes that integrate AI-generated cues with AR experiences in real-world settings. These prototypes serve as artifacts that actively explore the future of memory support. This work offers fresh insights into the interplay of AI, AR, and Human Memory, guiding the development of innovative approaches to potentially enhance memory.

Keywords: Human Memory enhancement, Artificial Intelligence, Augmented Reality, Spatial Memory, Method of Loci, Memory Palace Technique, Research through Design, Speculative Design.

Land Acknowledgement

I respectfully acknowledge that the land on which we gather is the traditional territory of the Mississaugas of the Credit First Nation, the Haudenosaunee Confederacy, the Anishinaabe, and the Huron-Wendat peoples. This land has been a site of human activity for over 15,000 years. It is the subject of the Dish with One Spoon Wampum Belt Covenant, an agreement between the Haudenosaunee Confederacy and the Anishinaabe and allied nations to share and care for the resources around the Great Lakes. Today, this meeting place is still home to many Indigenous people across Turtle Island, and we are grateful to have the opportunity to work and create on this land. We are committed to honouring Indigenous peoples' enduring presence and recognizing our responsibility in the journey toward reconciliation.

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1. Introduction

Memory is a fundamental component of human cognition, crucial for learning, decision-making, and performing daily tasks. Human memory involves encoding, storage, and retrieval processes but is also susceptible to forgetting. Hermann Ebbinghaus's forgetting curve illustrates how information is lost over time without reinforcement, demonstrating a rapid decline in memory retention shortly after learning (Ebbinghaus, 1850-1909, as cited in Wittman, ca. 2017) This natural tendency to forget poses challenges in an era of information overload, where traditional memory techniques often prove inadequate for managing the vast amounts of data encountered daily.

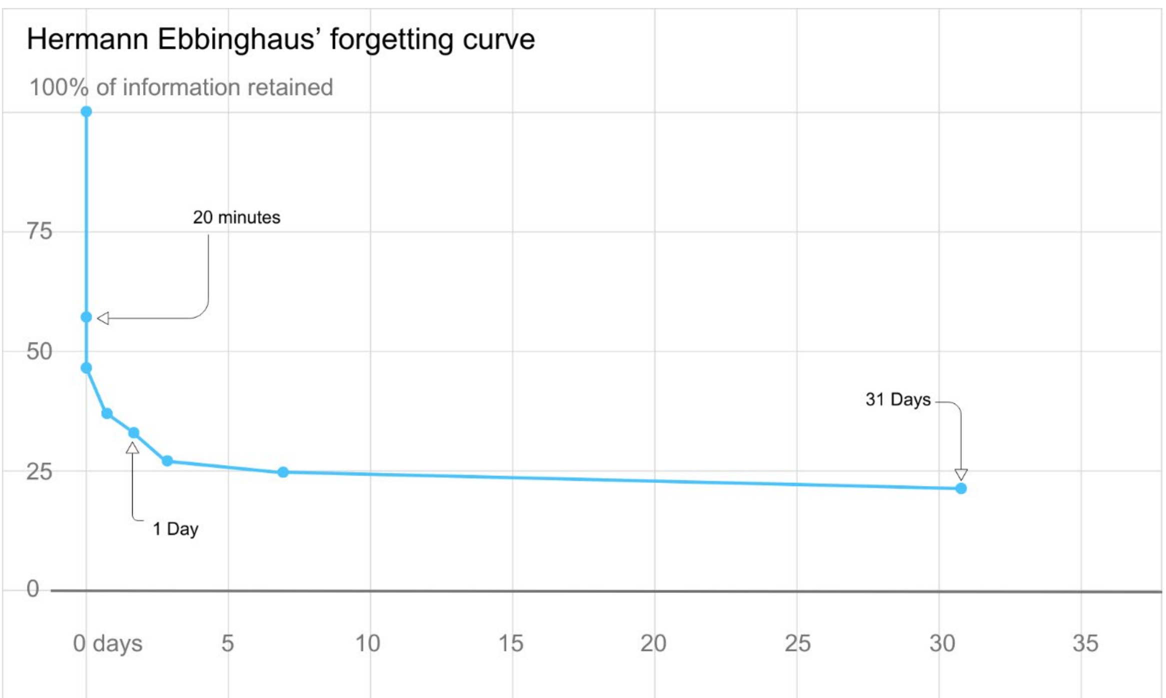

Figure 1: Ebbinghaus' forgetting curve (adapted from Psychology, 2020)

One of the oldest mnemonic strategies is the Method of Loci, which enhances recall by associating information with specific spatial locations. While effective, this technique demands significant mental effort and advanced visualization skills, making it less practical for everyone, especially in complex or information-dense contexts (Legge et al., 2012).

Advancements in digital technologies offer promising methods to support memory retention and retrieval. Integrating Artificial Intelligence (AI) and Augmented Reality (AR) provides innovative opportunities to augment cognitive processes. AI can tailor memory aids to individual users based on context and behaviour, while AR overlays digital elements onto the physical environment, creating immersive and interactive experiences. These technologies have shown significant potential in facilitating better memory performance through enhanced contextual cues and real-time feedback (Makhataeva et al., 2023).

Integrating AI into memory augmentation highlights significant strides in cognitive support systems. The development of Memoro exemplifies how large language models (LLMs) can create seamless, real-time memory aids. Memoro's dual interaction modes—Query Mode (user-initiated) and Query less Mode (context-inferred)—illustrate how technology can reduce cognitive load by adapting to the user's current task without explicit input (Zulfikar, Chan, & Maes, 2024). This approach emphasizes the potential for AI to make memory assistance intuitive and minimally intrusive.

The combination of AI and AR extends traditional memory enhancement techniques by reducing cognitive load and providing structured visual and spatial aids. Studies have demonstrated the effectiveness of virtual memory palaces, where individuals navigate virtual or augmented environments to encode and recall information. These virtual spaces improve memory retention and offer a more accessible approach to mnemonic strategies by leveraging technology to simulate familiar environments (Fassbender & Heiden, 2006; Huttner et al., 2018).

Despite the promise of AI and AR integration, significant gaps remain regarding their long-term efficacy and application in everyday life. Many studies focus on short-term memory enhancement in controlled environments, leaving questions about scalability and practical use unanswered. Additionally, ethical considerations surrounding AI's role in cognitive augmentation remain underexplored, particularly concerning privacy, dependency, and potential over-reliance on technology (Fischer, 2023).

Understanding AI and AR's nuanced roles in memory augmentation is essential as technology continues to intersect with human cognition. By delving into the challenges and opportunities presented by these innovations, this study aims to explore and develop tools that support human memory responsibly and effectively. Such insights can pave the way for solutions that enhance individual memory and provide guidelines, ensuring that technology serves as a mindful extension of human capacity rather than replacing it.

Taking a speculative approach, this study aims to address current challenges while anticipating future needs. By examining present conditions and identifying emerging possibilities, scenarios were constructed to explore both probable and preferable futures (as framed by the Futures Cone), focusing on a 1-to-5-year time horizon. Within this scope, it becomes feasible to imagine near-future interventions while still stretching beyond immediate market demands (Lutz, 2022). These scenarios then formed the basis for prototype development—artifacts designed to illustrate how memory augmentation might unfold in practical, immersive ways. By integrating speculative design principles (Kiialainen, 2022) and Research through Design (RtD) methodology (Gaver, 2012), the study demonstrates how iterative prototyping can illuminate potential pathways for AI and AR driven memory support.

1.1. Personal Motivation

My professional journey has spanned industries including industrial design, aerospace, defence, and higher education, eventually leading me to specialize in computational design and disruptive innovation. This diverse background has given me a unique perspective on how rapidly evolving technologies can optimize engineering processes while also transforming creative workflows and educational strategies in design.

Early in my career, I gravitated toward integrating computational tools into product design workflows, uncovering how algorithmic thinking and generative methods could both streamline ideation and reveal entirely new directions. Collaborations within sectors that prize accuracy, efficiency, and ingenuity, such as aerospace engineering or automotive systems, revealed the centrality of human cognition in complex problem-solving. Yet, even amid teams with deep expertise, I noticed that essential pieces of institutional and procedural knowledge would often fade, hampering the continuity of innovation.

As I shifted into my role as a tenured instructor in design education, the significance of robust memory retention and retrieval became even more pronounced. Working closely with design students encountering new theories and sophisticated computational tools, I regularly observed a common dilemma: Despite their enthusiasm and technical aptitude, many learners would forget foundational concepts or best practices after a few weeks. Ebbinghaus's classic forgetting curve emphasizes this human propensity to lose information without consistent reinforcement; my own classroom experiences and students' struggles brought that phenomenon to life in a stark way.

This sense of urgency around memory retention extended beyond academia. In professional studios, knowledge gaps caused by staff turnover, compartmentalized data, or simple forgetfulness frequently result in reduced efficiency and hindered creativity. Fascinated by how memory champions are able to remember information using traditional and modified techniques and by the emerging technologies in computational design and digital techniques, I began researching how new technologies, specifically Artificial Intelligence (AI) and Augmented Reality (AR), might bolster human cognitive capacities. AI-driven pattern recognition and AR-based contextual overlays, for instance, seemed poised to make memory support more dynamic and integrated into daily tasks.

2. Research Summary

2.1. Community of Practice

This work is a small part of a larger interdisciplinary Community of Practice (CoP) spanning human memory, artificial intelligence (AI), augmented reality (AR), speculative design, and human-computer interaction (HCI), with strong ties to OCAD University's Digital Futures program and the ACE Lab. This community is rooted in a collaborative ecosystem and comprises academics, researchers, designers, and technologists dedicated to exploring innovative AI and AR systems. The study benefits educators, cognitive scientists, UX researchers, and AI and AR developers, offering new insights into real-time memory augmentation tools. This study aims to strengthen knowledge exchange, speculative futures research, and the evolution of AI-powered cognitive tools.

2.2. What if

What if memory was no longer a passive recall process but an active, immersive experience shaped by Artificial Intelligence (AI) and Augmented Reality (AR)?

Imagine a world where digital cues seamlessly overlay onto our physical surroundings, transforming everyday spaces into dynamic knowledge repositories. Traditional memory techniques like the Method of Loci, once reliant on visualization and mental effort, could evolve into an AI-powered augmentation that anchors information directly into real-world locations via AR overlays. Walking through a city might trigger automatic recall of past experiences, historical insights, or personal reminders, making memory retrieval an intuitive, ever-present layer of reality. This integration can reduce cognitive load, enhance long-term memory storage, and redefine human cognition by externalizing aspects of memory into the built environment.

Figure 2: A sketch depicting an imaginary world

2.3. Research Question

Primary Research Question

How might we integrate Artificial Intelligence (AI) and Augmented Reality (AR) technologies to utilize spatial memory techniques, such as the Method of Loci, by creating immersive and spatial experiences that enrich human memory retention, recall, and overall quality of life?

Secondary Research Questions

- How might immersive AR cues trigger and enhance tangible memory recall in everyday settings?
- In what ways could AI and AR transform real-world locations into personalized memory palaces to aid spatial recall?
- How can AI-enhanced vision provide on-the-fly annotations to facilitate real-time memory retrieval?
- How might conversational AI proactively strengthen memory through contextual and timely prompts?
- What methods might enable AI to generate interactive 3D memory experiences from descriptive inputs?

2.4.Aims and Objectives

The primary aim of this research is to investigate how Artificial Intelligence (AI) and Augmented Reality (AR) can enhance human memory retention and recall by integrating spatial memory techniques, such as the Method of Loci, into immersive, world-scale experiences. This study explores technological advancements, existing limitations, and potential future directions for AI-AR-based cognitive augmentation.

The key objectives of this research are:

- To analyze the foundations of human memory systems and the Method of Loci, examining its effectiveness in memory retention and identifying gaps in existing technological adaptations.
- To explore advancements in AI-driven multimodal technologies, evaluating their potential for developing large-scale, AI-enhanced Method of Loci experiences.
- To experiment with various AR tools and platforms, assessing their capabilities in creating immersive overlays that enhance the spatial and interactive components of the Method of Loci.
- To investigate the integration of AI and AR technologies, developing dynamic, context-aware memory augmentation systems that personalize memory retrieval based on user interactions and real-world environments.
- To develop speculative artifacts and conceptual prototypes, illustrating how AI and AR can be utilized to create enhanced memory experiences.

To evaluate and analyze AI-AR prototypes, assessing their performance, features, and effectiveness, identifying what worked and what did not through iterative Research through Design (RtD) methodologies within a Speculative Futures framework.

2.5.Methodologies

Augmenting human memory through artificial intelligence (AI) and augmented reality (AR) presents a complex problem space that traditional research methods may find challenging to fully address. In this context, a design-led inquiry offers a compelling approach by treating the act of designing as a mode of investigation. Speculative design methodologies (Dunne & Raby, 2013) set the stage for these inquiries by posing “what if” scenarios that challenge existing assumptions and foster critical debate about potential social and ethical dimensions. Building on this imaginative groundwork, Research through Design (RtD) (Gaver, 2012) employs methods and processes from design practice as a legitimate mode of inquiry, emphasizing that creating artifacts can generate new knowledge. Through iterative cycles of prototyping and reflection, this research approach provides a creative way of investigating potential futures, allowing insights to emerge organically from the making process. Crucially, such design-led methodologies prioritize exploration and understanding over immediate commercial outcomes, with design-oriented action undertaken not for an instant product but for broader conceptual insight. This foundation is invaluable for AI and AR-driven memory augmentation, as it enables open-ended, human-centred exploration of cognitive phenomena and future use cases that may be unclear or difficult to examine using conventional methods. When integrated with RtD, speculative design enables iterative prototyping to extend beyond mere functionality, illuminating emerging possibilities and ultimately broadening our collective understanding of how human memory can be augmented in meaningful ways.

2.6.Contributions

This research advances a design-led framework for integrating Artificial Intelligence (AI), Augmented Reality (AR), and mnemonic techniques to enhance human memory. It aligns theoretical constructs of memory with emerging multimodal technologies. The study demonstrates feasibility through proof-of-concept designs and an extensive literature review that contextualizes AI and AR innovations in memory augmentation. A descriptive evaluation approach reveals where and how these integrated solutions can most effectively be applied.

- **Literature Synthesis:** Compiles and analyzes diverse sources on memory science, speculative design, and AI/AR approaches, grounding the research in interdisciplinary theory.
- **Integration Framework:** Formulates a systematic way to combine AI-driven experiences, AR overlays, and traditional mnemonic methods.
- **Proof-of-Concept Prototypes:** Validates the integration strategy by illustrating multiple design pathways and potential user experiences.
- **Descriptive Evaluation Approach:** Establishes criteria and contexts demonstrating the practical relevance of these methods, guiding future development and application.

2.7. Scope

This work focuses on the design and conceptual exploration of future digital mnemonic systems utilizing Artificial Intelligence (AI) and Augmented Reality (AR) technologies. Employing a speculative design and research-through-design methodology, the aim is to envision how classical mnemonic techniques, specifically the Method of Loci, can be transformed into innovative, technology-enhanced memory aids.

This work is explicitly in scope for:

- Conceptual design involving speculative prototypes to explore potential applications of AI and AR for memory enhancement.
- Research-through-design approaches generate insights through iterative experiments and reflective analysis.
- Technical explorations investigating functional and interaction aspects of incorporating AI and AR into mnemonic systems.

This work is explicitly out of scope for:

- This research does not focus on memory measurement or neuroscience validation.
- While visual design is considered, artistic aesthetics are not a primary focus.
- Usability tests, along with qualitative and quantitative user evaluations, are out of scope due to the implementation of speculative design methodologies and Research through Design (RtD).
- The research does not evaluate business potential, viability, or pricing strategies.
- Classical techniques beyond the Method of Loci may be acknowledged but are not deeply investigated without an AI/AR component.
- Although privacy, data security, and ethical implications of AI/AR are recognized, detailed policy guidelines or regulatory frameworks are beyond the scope.
- Detailed exploration of inclusive design or robust safety features for prototypes is not part of this effort.

The core objective is to stimulate discussion and reflection on the potential of AI and AR in memory augmentation through design-led exploration, rather than delivering immediately applicable, empirically validated solutions.

2.8. Limitations

This research, employing a speculative design approach, is limited by the absence of formal user validation. Without rigorous user studies or empirical evaluations, the effectiveness and usability of the proposed AI and AR-enhanced mnemonic prototypes remain unquantified. Assessments rely on the researcher's reflective analysis, introducing inherent subjectivity. Resource and time constraints further limited the scope, impacting the depth of exploration in areas like artistic aesthetics and emotional resonance, as the focus prioritized technical design.

Consequently, the findings are exploratory and illustrative rather than empirically proven. The lack of diverse user testing restricts generalizability, and the speculative nature of the prototypes limits their direct applicability to real-world scenarios. Therefore, the conclusions should be interpreted as potential possibilities, acknowledging that further research with empirical validation is necessary to fully assess their practical implications.

2.9. Chapter Overview

This thesis is composed of nine chapters. Chapters 1 and 2 introduce the background and provide a research summary, which includes the community of practice, the “What if?” question, the research question, aims and objectives, methodologies, contributions, scope, and limitations. Chapter 3 offers a comprehensive literature and contextual review, covering human memory foundations, mnemonic techniques, the method of loci, and technological advancements, along with critical analysis and future directions. Chapter 4 presents related work through various case studies. Chapter 5 explains the methodology, focusing on speculative design and Research through Design. Chapter 6 details the “What if?” scenarios and iterative prototypes, while Chapter 7 provides an evaluation and analysis of these prototypes. Chapter 8 concludes the thesis with final reflections and future directions. Finally, Chapter 9 lists the references. See Figure 3 for the overall structure of the thesis.

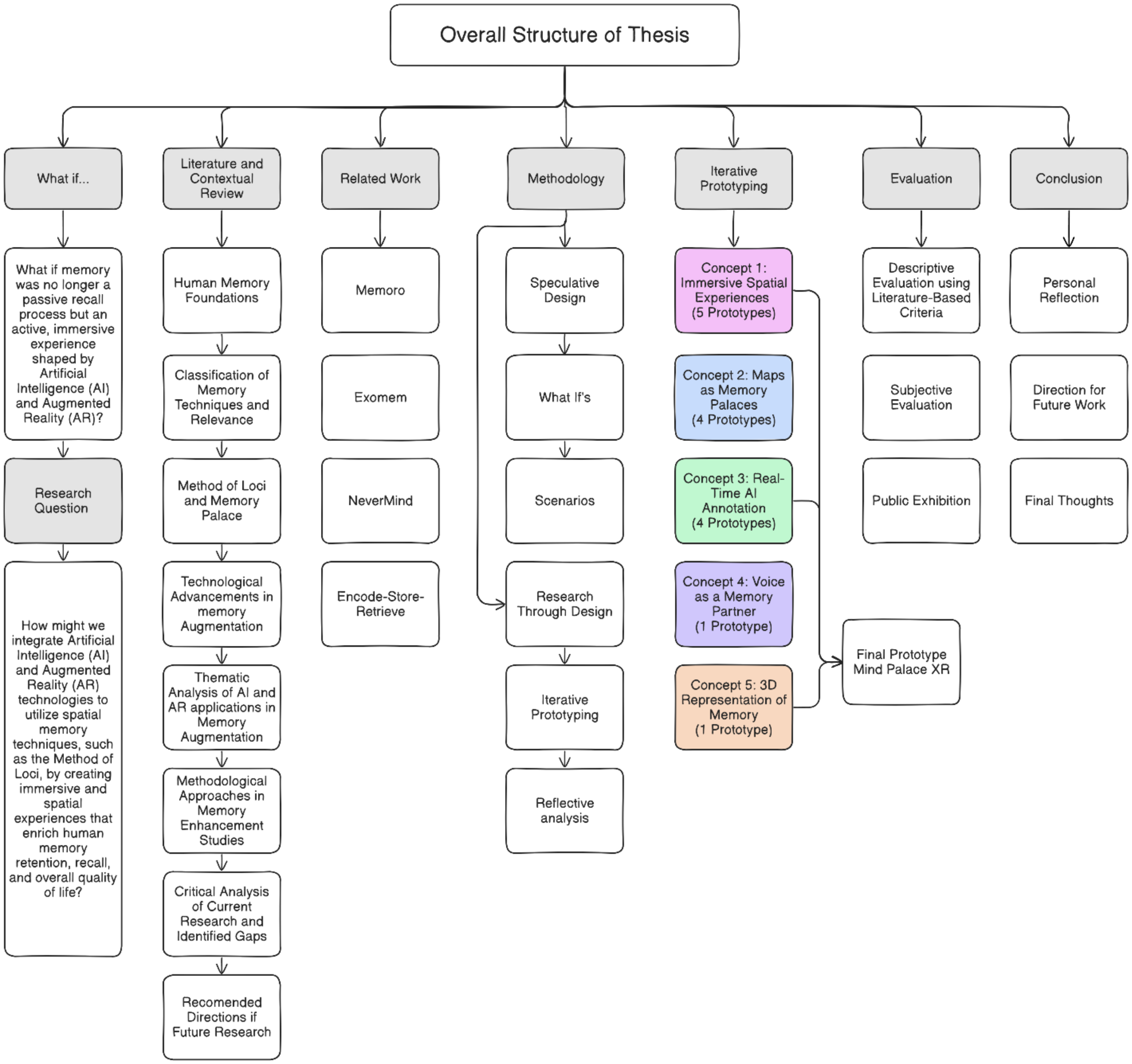

Figure 3: Overall thesis structure

3. Literature and Contextual Review

3.1. Structure

This literature review starts with an exploration of human memory foundations, followed by an examination of the method of loci as a key mnemonic strategy. It then investigates the technological advancements in memory augmentation (including AI and AR), reviews methodological approaches, provides a critical analysis of current research and identified gaps, and concludes with recommended directions for future research.

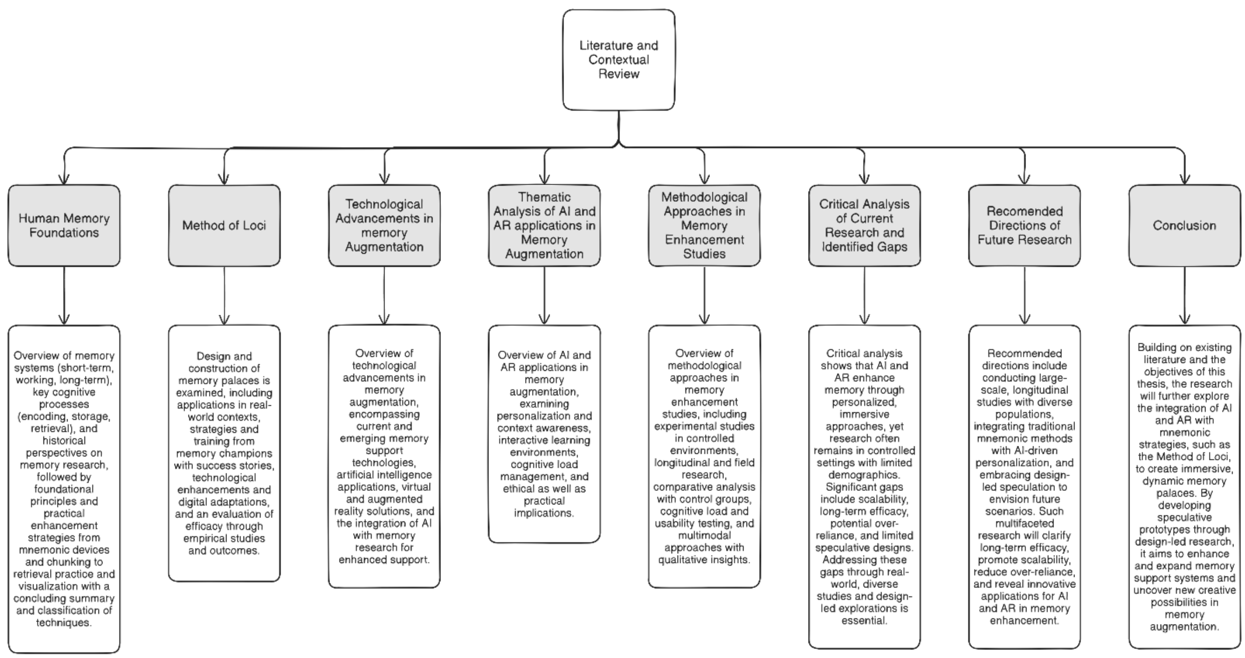

Figure 4: Structure of literature and contextual review

3.2. Human Memory and Foundations

Human memory has long been a subject of inquiry, and its theoretical foundations are built on the idea that memory is not a single, monolithic faculty but a collection of processes and systems. Early psychologists grappled with fundamental questions: What is memory? Is it one thing or many? Answers to these questions were not immediately apparent; indeed, the very concepts and categories we use now (e.g. distinguishing different memory types and stages) had to be established over time (Squire & Wixted, 2011). A core theoretical principle that emerged is that memory involves multiple systems or stores. As far back as the late 19th century, William James proposed a distinction between primary memory (the immediate contents of consciousness) and secondary memory (stored information) (Norris, 2017). This introspective insight laid the groundwork for the later idea that the human mind maintains separate memory stores for immediate experience versus long-term retention (Norris, 2017). In parallel, theorists recognized that memory operates through distinct processes – the encoding of information, its retention, and subsequent retrieval – rather than functioning as a single act. This process-oriented view became another pillar of memory theory, conceptualizing memory as an information-processing system through stages.

Another foundational concept is that remembering is not a literal replay of past events but often a constructive process. Frederic Bartlett's seminal work in 1932 challenged earlier notions of memory as a faithful recording device. Bartlett provided evidence that recall is an "imaginative reconstruction" of past events influenced by an individual's schemas (organized knowledge structures) (Schacter, 2012). In other words, people actively reconstruct memories using prior knowledge, which can lead to distortions. This idea – that memory is fallible and shaped by cognitive frameworks – was radical at the time and has since become a cornerstone of cognitive memory theory. It foreshadowed modern research on false memories and the role of prior knowledge in remembering. These theoretical foundations (multiple memory systems, staged processes, and constructive reconstruction) have framed much of the subsequent research into human memory. They provide a lens for understanding how we form, store, and recall experiences, setting the stage for differentiating specific memory systems and mechanisms in the sections that follow.

3.2.1. Overview of Memory Systems (Short-term, Working, Long-term)

The study of human memory identifies several interacting systems, each with distinct characteristics. A fundamental division is between short-term memory (STM) and long-term memory (LTM). Short-term memory (immediate or primary memory) is a temporary storage with limited capacity. Classic experiments demonstrated that STM can hold only about roughly 7 ± 2 items at once (Chekaf et al., 2016). For example, most adults can remember a phone number of seven digits, but this capacity can be increased through chunking – grouping individual bits of information into more significant, meaningful units (Chekaf et al., 2016). STM retains information for seconds unless one actively maintains it (such as by rehearsal). To better account for the active manipulation of information in the short term, the concept of working memory (WM) was introduced. Working memory refers to a limited-capacity system responsible not just for briefly holding information but also for processing and manipulating it. In a landmark model, Baddeley and Hitch (1974) proposed that working memory has multiple components: a phonological loop for verbal information, a visuospatial sketchpad for visual/spatial data, and a central executive to allocate attention and coordinate the subsystems (Adams et al., 2018). This model explained why we could, for instance, rehearse a phone number (verbal loop) while visualizing a route on a map (sketchpad) with minimal interference. Working memory, in effect, broadened the concept of short-term memory to include both storage and cognitive control. Researchers often distinguish the two by context: if one simply holds information (e.g. repeating a list of digits), that taps short-term memory, whereas simultaneously holding and mentally reversing those digits would recruit working memory (Adams et al., 2018).

By contrast, long-term memory is the system for relatively permanent storage of information. Long-term memory has a vastly larger capacity and retains information from minutes to a lifetime. Decades of research have shown that LTM is not a single unit; it encompasses multiple subsystems. A major distinction is between declarative (explicit) memory - memories that can be consciously recalled, such as facts and events - and non-declarative (implicit) memory - unconscious memories, such as skills and habits (Mujawar et al., 2021). Declarative memory itself is often subdivided into episodic memory (memory for personal experiences and specific events in time) and semantic memory (general knowledge and facts) (Mujawar et al., 2021). These forms of memory rely heavily on the medial temporal lobe and hippocampus for their formation (Mujawar et al., 2021). Nondeclarative memory includes abilities like procedural memory (e.g. riding a bike), priming, and simple conditioning, which are supported by other brain systems (e.g. cerebellum, basal ganglia) and do not require conscious recollection (Mujawar et al., 2021). The evidence for distinct memory systems comes from multiple sources: behavioural experiments, which show different properties (duration and capacity) for STM/WM vs. LTM, and neuropsychological cases. For instance, patients with damage to the hippocampus (such as the famous case of Henry Molaison, “H.M.”) can often maintain standard short-term memory but are unable to form new long-term episodic memories, demonstrating a clear separation between short-term and long-term storage systems in the brain (Squire & Wixted, 2011). Since the 1960s, nearly all cognitive models have embraced the idea of multiple memory stores (Norris, 2017), a short-term store for immediate information and a long-term store for enduring information, as a foundational assumption. This multi-store framework, articulated initially by Atkinson and Shiffrin (1968), remains influential (Norris, 2017), with modern refinements differentiating the nuanced roles of working memory and various long-term memory subsystems.

3.2.2. Key Cognitive Processes (Encoding, Storage, Retrieval)

When we remember something, we typically traverse three key cognitive processes: encoding, storage, and retrieval. Encoding is the initial process of transforming perceptions and thoughts into a form that can be stored in the brain. It is often described as the learning or acquisition phase, where new information is attended to and processed. Effective encoding can involve making information meaningful. For example, forming associations or linking new material to existing knowledge greatly enhances later recall. On a neurobiological level, encoding corresponds to changes in neural circuitry; as information is encoded, the brain creates memory traces (also called engrams) through processes like synaptic plasticity. However, not all encoded information will be retained. The next phase, storage, refers to maintaining information over time. This can be seen as the preservation of encoded information in memory, whether for a few seconds or an entire lifetime. Some information is stored only transiently (as in short-term memory), while other information undergoes consolidation – a process of stabilization that integrates new memories into long-term storage. Consolidation often occurs over hours to days and is thought to involve the reorganization of brain networks. The final phase is retrieval, which is the process of accessing stored information when it is needed. Retrieval is what we experience as “remembering”; it can be recall (intentionally bringing a memory to mind) or recognition (identifying a familiar piece of information as such).

Each of these processes is essential and subject to its own principles and potential errors. Importantly, they are interrelated: successful long-term memory requires effective encoding and consolidation, and successful retrieval depends on how well information was encoded and how it was stored. Research shows that retrieval is cue-dependent; memories are accessed by prompts or cues that trigger the stored information (Frankland et al., 2019). In fact, a classic principle known as encoding specificity holds that retrieval is most effective when the cues present at recall match those present during encoding (Frankland et al., 2019). For example, if you encoded a fact while listening to a particular song, hearing that song later may cue the recall of that fact. Failures of memory often occur when encoding is shallow (resulting in weak or unstable storage) or when appropriate retrieval cues are absent. It is also now understood that retrieval itself is a reconstructive act; recalling a memory can alter it, and repeated retrieval can strengthen the memory trace. The steps of encoding, storage, and retrieval can thus be seen as a continuous cycle in memory formation. Cognitive psychologists emphasize that memory is dynamic: we actively encode information (often employing strategies to make encoding richer), we retain it with varying levels of fidelity, and we reconstruct it in retrieval, which can update or even distort the original memory. This trio of processes provides a framework for understanding how information moves through the memory system, from our initial perception of an event to our later recollection (Mujawar et al., 2021).

3.2.3. Key Historical Perspectives

The scientific exploration of memory began in the late 19th century, establishing perspectives that still resonate today. One of the first rigorous studies of human memory was conducted by Hermann Ebbinghaus in the 1880s. Ebbinghaus taught himself lists of syllables and tested his recall over time, quantitatively charting how memory faded. His work produced the famous forgetting curve, showing that memory loss is rapid soon after learning and then levels off over extended periods. This approach demonstrated that memory could be studied experimentally and mathematically. In replicating Ebbinghaus's findings, modern researchers have confirmed the general shape of the forgetting curve (Murre & Dros, 2015). Ebbinghaus's perspective was that memory operates through basic associative mechanisms and that repetition and time determine retention.

In contrast to Ebbinghaus's focus on isolated material, William James and later Frederic Bartlett offered more holistic perspectives. William James, in The Principles of Psychology (1890), not only differentiated immediate vs. long-term memory (primary vs. secondary) as noted earlier, but also distinguished memory from habit (Mujawar et al., 2021). By "memory," James meant the conscious recollection of experiences, whereas "habit" referred to automated routines and skills. This presaged the modern distinction between declarative memory for events and procedural memory for skills. James's introspective observations highlighted that remembering involves both information and emotion – he noted, for example, the influence of interest and significance on what we remember, adding a functional, qualitative angle to early memory theory.

Frederic Bartlett's work in the early 20th century (notably his 1932 book Remembering) provided a social-cultural perspective on memory. Bartlett had people recall stories and pictures and observed that their recollections were not verbatim but were systematically transformed. He concluded that remembering is guided by schemas, which are organized knowledge structures reflecting an individual's prior experiences and cultural background (Schacter, 2012). Bartlett's participants tended to unintentionally omit details that did not fit their expectations and to add or normalize details to make the story more coherent with their cultural schemas. This was a stark departure from the prevailing view of memory as a passive repository. Bartlett's perspective emphasized that memory is constructive and subject to error. Initially, Bartlett's ideas were not fully appreciated in an era dominated by behaviourism (which eschewed the study of unobservable mental processes like memory). However, his work gained recognition later and is now seen as a forerunner to modern cognitive and schema-based theories of memory (Schacter, 2012).

Between Ebbinghaus's experimental rigour and Bartlett's demonstration of reconstructive remembering, the early landscape of memory research was rich with insights. However, after these pioneering studies, research on memory waned somewhat during the first half of the 20th century under the influence of behaviourism, which focused on observable behaviour and largely sidelined topics like memory and imagery. In this period (circa 1920s–1950s), the study of memory persisted mainly in the form of verbal learning research, which was essentially an extension of Ebbinghaus's paradigm to more meaningful materials and in clinical observations of memory disorders. It was not until the cognitive revolution of the mid-20th century that memory research surged back to the forefront of psychology. The historical perspectives contributed by Ebbinghaus, James, and Bartlett (among others) then provided a foundation for this resurgence, offering complementary views: memory as a quantifiable mechanism, memory as a functional differentiation of mind, and memory as an active, schema-driven process. These perspectives emphasized that memory could be studied scientifically while also being profoundly influenced by meaning and context – a duality that continues to shape contemporary memory research.

3.2.4. Evolution of Memory Research

Over the past century, the study of memory has evolved from simple experimental demonstrations to a sophisticated, interdisciplinary science. Following the early groundwork laid in the 1880s–1930s, there was a transformative period in the 1950s and 1960s, often referred to as the Cognitive Revolution. During this period, psychologists returned to studying internal mental processes, armed with new theories and methods. A key catalyst was the case of Henry Molaison (H.M.), who, in 1953, underwent brain surgery that left him unable to form new long-term memories. A careful study of H.M. by Brenda Milner and colleagues in the late 1950s demonstrated conclusively that short-term and long-term memory are biologically distinct (H.M.'s. short-term memory was intact, but he had profound long-term memory impairment). Work with H.M. established "key principles about the organization of memory that inspired decades of experimental work." (Squire & Wixted, 2011) The impact of this case on memory research can hardly be overstated – it steered scientists toward the idea of multiple memory systems and spurred extensive research into the medial temporal lobe, memory consolidation, and amnesia.

At the same time, experimental psychologists were developing formal models of memory. Richard Atkinson and Richard Shiffrin's (1968) multi-store model encapsulated the emerging consensus by describing memory as an information-processing system with sensory memory, a short-term store, and a long-term store. This model synthesized earlier findings and provided a testable framework that dominated research for years (Norris, 2017). In 1972, Endel Tulving proposed the distinction between episodic and semantic memory, further refining the architecture of long-term memory. In 1974, Baddeley and Hitch introduced the multi-component working memory model, reflecting experimental evidence that short-term retention involves active manipulation and distinct subsystems (Adams et al., 2018). These theoretical advances marked the 1960s–1970s as a period of major breakthroughs, effectively bridging the gap between abstract cognitive theory and observable behaviour. Concurrently, researchers like George Miller had already drawn attention to the capacity limits of immediate memory (his famous 1956 paper, "The Magical Number Seven, Plus or Minus Two," highlighted the limited span of short-term memory and introduced the concept of chunking) – one of the most cited papers in psychology (Cowan, 2015). Such findings dovetailed with the new models and gave researchers concrete phenomena to explain.

From the 1980s onwards, the evolution of memory research has been characterized by increasing integration with neuroscience. The rise of cognitive neuroscience brought tools like brain imaging (fMRI, PET) and electrophysiology to bear on questions about memory, allowing scientists to observe memory processes in the living brain. Studies began to map where and how memories are stored. For example, researchers identified networks for explicit memory (centred on the hippocampus and cortical areas) versus implicit memory (involving the basal ganglia, cerebellum, etc.). The concept of multiple memory systems was solidified by convergent evidence from neuroimaging and patient studies (Squire & Wixted, 2011). In parallel, neurobiological research at the cellular level (pioneered by scientists like Eric Kandel) illuminated memory's molecular foundations. Kandel's work on sea slugs in the 1960s–1980s uncovered that memory formation involves changes in synaptic strength (long-term potentiation and new protein synthesis), for which he was awarded the Nobel Prize in 2000 (Mujawar et al., 2021). This line of work linked the abstract concept of "storage" to concrete cellular processes, bridging psychology and biology.

As the field progressed into the 21st century, memory research has become truly interdisciplinary. Psychologists, neuroscientists, computer scientists, and others are collaboratively exploring memory. New research areas have emerged, such as the study of prospective memory (remembering to do things in the future), autobiographical memory in natural settings, and memory modulation (how factors like stress or emotion enhance or impair memory storage). There is also a strong interest in memory distortions and false memories, fueled by findings that even confident recollections can be inaccurate (building on Bartlett's early insights). The evolution of memory research thus reflects a broadening scope: from simple lists in the lab to rich, complex phenomena in real life and from behaviourist avoidance to full embrace of the mind/brain level of analysis. What began as a largely philosophical or experimental psychology question has turned into a multidisciplinary enterprise spanning from synapses to subjective experience. Throughout this evolution, foundational principles (such as the distinction between memory systems and the stages of encoding–storage–retrieval) have remained central, even as methods and theoretical nuances have grown more sophisticated. The trajectory of memory research illustrates an increasingly detailed understanding of what memory is and how it works, setting the stage for leveraging this knowledge in practical applications and interventions.

3.2.5. Early Theories and Breakthroughs

The development of memory research is punctuated by several early theories and empirical breakthroughs that shaped our understanding of how memory works. One of the earliest was Ebbinghaus's memory theory of passive association and decay, exemplified by his discovery of the forgetting curve in the 1880s. Ebbinghaus theorized that memories weaken over time in a lawful manner, and his method of savings experiments quantified this decay (Murre & Dros, 2015). This was a breakthrough in demonstrating that mental processes like forgetting follow predictable patterns – a finding that laid the groundwork for later theories of decay and interference in memory. Around the same time, William James put forward theoretical distinctions that were remarkably prescient. He theorized a separation between short-term and long-term memory (using terms like primary and secondary memory), as well as between memory for events and habits/skills (Mujawar et al., 2021). James's insights did not immediately translate into experimental breakthroughs, but conceptually, they were foundational, foreshadowing distinctions that would only be empirically confirmed decades later.

Moving into the 20th century, Bartlett's schema theory (1932) was a major theoretical breakthrough. Bartlett argued that memory uses schemas and is subject to systematic errors, countering the then-dominant idea that memory is primarily a reproductive process. Although Bartlett's theory took time to gain traction, it eventually inspired extensive research into how prior knowledge and expectations shape memory encoding and retrieval. Another key milestone was the work of Wilder Penfield in the 1940s and 1950s, who found that stimulating certain brain areas could elicit vivid, apparently forgotten memories in epilepsy patients. While not a "theory" per se, this finding hinted at the physical localization of memory and the richness of stored experiences, contributing to emerging theories about memory trace storage in the cortex.

The mid-20th century brought a cascade of breakthroughs. In 1953, the case of patient H.M. (Henry Molaison) provided the first clear evidence for the division of memory systems. After H.M.'s hippocampal surgery, researchers Brenda Milner and colleagues reported that he could no longer form new long-term memories, though his short-term memory and intellect were intact. This finding demonstrated the critical role of the medial temporal lobe in long-term memory and empirically validated the concept of separate memory stores – a core assumption of many subsequent models (Squire & Wixted, 2011). In 1956, George Miller's paper on the magical number seven became a landmark in short-term memory research. Miller noted a standard limit of about seven items across various tasks (e.g. digit span) and introduced the idea of chunking as a strategy to overcome this limit. This not only quantified STM capacity but also suggested that how information is encoded (grouping bits into meaningful chunks) can expand functional memory capacity (Chekaf et al., 2016). Miller's work is one of the most cited in psychology, underscoring its status as a breakthrough in revealing a fundamental property of human memory (Cowan, 2015).

Building on such findings, the late 1960s and early 1970s saw the formulation of integrative memory theories. The Atkinson-Shiffrin modal model (1968) was one: it formally proposed distinct stages (sensory memory, short-term store, long-term store) and introduced control processes (like rehearsal) that govern information flow between them. This model synthesized many past observations and became a standard framework (Norris, 2017). Close on its heels, Craik and Lockhart's Levels-of-Processing theory (1972) offered a different perspective: They suggested that retention depends on the depth of processing (from shallow sensory analysis to deep semantic analysis) rather than on which store the information resides. Their experiments showed that semantically processed words were remembered better than superficially processed ones, challenging purely structural models and emphasizing encoding processes. In 1974, Baddeley and Hitch's Working Memory model revolutionized the concept of short-term memory by splitting it into multiple components and highlighting the role of active manipulation (Adams et al., 2018). This was a theoretical breakthrough explaining phenomena (like doing two tasks at once) that the single STM box of earlier models struggled with. Around the same time, Endel Tulving proposed the distinction between episodic and semantic memory (1972) and later between remembering and knowing (recollection vs familiarity) – theoretical distinctions that spurred targeted research and remain influential in how we think about long-term memory structure.

In summary, early theories and breakthroughs in memory research established both structure and process: from Ebbinghaus's quantitative laws of forgetting to James's qualitative distinctions, from Bartlett's schemas to the dramatic demonstration of memory systems in H.M., and from Miller's STM capacity to the multi-component models of the 1960s–70s (Norris, 2017) (Adams et al., 2018). Each of these milestones addressed fundamental questions about memory and provided a platform for future research. They clarified that memory is not a unitary faculty but has distinguishable parts and dynamics, and they offered initial answers to how and why we remember or forget. These early insights continue to inform contemporary theories, even as modern research builds upon and refines them.

3.2.6. Relevance to Modern Applications

Research on human memory is not only of theoretical interest – it has significant practical implications across education, clinical contexts, technology, and daily life. One central area of application is education and learning. Findings from cognitive psychology have led to improved study techniques and instructional methods. For example, the discovery of the spacing effect and the testing effect (retrieval practice) has informed how educators advise students to study. Rather than mass cramming, students are encouraged to use spaced repetition and frequent self-quizzing, strategies demonstrated to yield more durable learning (Sleister, 2014). Empirical evidence shows that spacing out study sessions and actively retrieving information from memory produce better long-term retention than rereading material in a short span (Sleister, 2014). Many modern educational tools and apps (such as digital flashcard programs) are explicitly based on these memory principles, adjusting review schedules to optimize memory retention. Thus, foundational memory research directly translates into strategies that improve academic performance and skill acquisition.

Memory research also finds application in the design of technology and user interfaces. Understanding the limits of working memory, for instance, helps interface designers avoid overloading users with too much information at once. The practice of breaking information into smaller chunks – whether a phone number is segmented into groups of digits or menu options grouped logically in software – stems from our knowledge of memory capacity and chunking (Chekaf et al., 2016). Likewise, website and instructional designers leverage the idea that people remember beginnings and ends better than middles (the serial position effect) by placing important items accordingly. In the legal field, memory research on eyewitness testimony has led to reforms in how police lineups and interviews are conducted. Knowing that memory is reconstructive and vulnerable to suggestion, law enforcement agencies have adopted protocols (e.g. the cognitive interview technique) that improve the accuracy of eyewitness recollections and minimize inadvertent memory distortions. These changes are rooted in decades of findings about factors that influence retrieval and false memories.

Clinically, the relevance of memory research is evident in interventions for memory impairments and in mental health. Neuropsychological rehabilitation for patients with brain injury or dementia often employs memory enhancement techniques (like spaced retrieval practice for Alzheimer's patients or errorless learning methods) that emerged from cognitive research. For example, therapists might use spaced practice to help a person with amnesia gradually learn and retain important facts or skills, capitalizing on the spacing effect to bolster what remains of their memory capability. Research on context-dependent memory and encoding specificity has informed practices like training individuals in environments similar to where they must later perform (helpful in training first responders or pilots, for instance, so that retrieval cues during training match real-world conditions) (Frankland et al., 2019). Even ordinary individuals benefit from memory research in their daily lives. Strategies for improving one's own memory – from mnemonic techniques to simply understanding the importance of attention and elaboration when learning – come straight from experimental findings. Popular science books and courses often distill this research (e.g. advising students to "mix up your practice, test yourself, and spread out your study sessions" based on evidence (Sleister, 2014). In sum, the scientific study of memory has yielded actionable insights that permeate many aspects of modern life. By applying these principles, we can design better educational programs, create user-friendly technologies, craft fairer legal procedures, and develop interventions to assist those with memory difficulties, thereby directly translating foundational memory theories into real-world benefits.

3.2.7. Foundational Principles Informing Contemporary Memory Enhancement Techniques

Several fundamental principles uncovered by memory research form the basis of modern techniques for enhancing memory. One such principle is the spacing effect – the finding that information is remembered better when learning sessions are distributed over time rather than massed in short intervals. First documented by Ebbinghaus in 1885 and repeatedly confirmed since the spacing effect shows that "repetitions spaced in time tend to produce stronger memories than repetitions massed closer together in time." (Smith & Scarf, 2017) This foundational principle directly informs contemporary spaced learning and repetition schedules. Many language-learning and flashcard software, for example, use spaced intervals to present information at optimally timed gaps, a practice rooted in over a century of spacing effect research. Another core principle is the retrieval practice effect (often called the testing effect). Research has demonstrated that actively recalling information (for instance, via quizzes or practice tests) strengthens memory more than passive review. Practicing retrieval is essentially exercising the memory trace; each successful recall makes the memory more retrievable in the future. Modern educational approaches leverage this by incorporating frequent low-stakes testing and self-quizzing, a direct application of the laboratory finding that retrieval practice, especially when spaced and interleaved with other topics, leads to more durable, conceptual learning (Sleister, 2014). Thus, the effectiveness of techniques like flashcards or practice exams is not just anecdotal – it is grounded in empirical principles of how memory encodes and retains information through retrieval.

Another foundational memory principle is the importance of depth of processing. Studies by Craik and colleagues in the 1970s showed that the more meaningfully one processes information at encoding (for example, thinking about a word's meaning or relating it to oneself), the better that information is remembered. This principle underlies strategies of elaborative encoding used today: Learners are encouraged to paraphrase information, form examples, or create associations, thereby engaging in deeper semantic processing that improves recall. Relatedly, the principle of organization in memory – that well-organized information is easier to remember – has given rise to techniques like concept mapping and hierarchical outlines for study, which help impose structure on the material in line with how memory naturally groups related items.

The classical idea of chunking as a memory mechanism (noted by Miller and others) is also employed in modern memory enhancement. Because human working memory has limited slots, combining individual bits into larger "chunks" allows one to hack those limits (Chekaf et al., 2016). Contemporary mnemonic systems explicitly teach chunking methods – for example, breaking a long number into memorable dates or grouping items of a list into categories – so as to improve immediate recall and lay the stronger groundwork for long-term storage. This strategy reflects the principle that memory efficiency improves when information is recoded into a compressed, meaningful form (Chekaf et al., 2016).

Perhaps the most vivid examples of principles-to-practice are mnemonic techniques that harness imagery and association. One ancient principle rediscovered by modern science is that visual imagery and spatial cues dramatically boost memory. The method of loci (memory palace technique) operates on the principle that humans have excellent spatial memory and that associating abstract information with vivid mental images in a familiar spatial layout makes it far more memorable. Research on memory champions has confirmed that "mnemonic techniques, such as the method of loci, can powerfully boost memory," leading to long-lasting recall improvements when people are trained in their use (Wagner et al., 2021). The success of this technique in both laboratory and real-world competitions underscores a fundamental memory principle: association. By linking new information to well-established memories (like locations on a familiar route), we create multiple retrieval pathways and richer encodings, which in turn facilitate later recall. Modern memory enhancement courses frequently teach the loci method, peg-word systems, or acronym mnemonics – all of which rely on the principle that meaningful, interactive cues (whether visual, verbal, or conceptual) enhance the encoding and retrieval of target information.

In summary, contemporary memory enhancement strategies did not arise in a vacuum; they are grounded in key principles discovered through decades of research. The spacing effect, retrieval practice, depth of processing, organization/chunking, and associative imagery are foundational concepts that have each given rise to practical techniques. By applying these principles, one can move beyond naive approaches like rote repetition and instead use scientifically informed methods to substantially improve memory performance. The close alignment between these principles and modern strategies highlights the translational power of memory research – from theory in the lab to techniques in the classroom or daily life.

3.2.8. Applied Memory Enhancement Strategies

Drawing on the above principles, various applied strategies have been developed to deliberately improve memory performance. These memory enhancement strategies range from specific mnemonic tricks to general lifestyle approaches aimed at optimizing encoding or retrieval.

3.2.8.1. Method of Loci

The Method of Loci, or memory palace technique, uses spatial locations as a framework for memorization. Learners visualize placing each item to remember at specific familiar locations (loci) along a mental journey, such as rooms in a house or landmarks on a route (Sousa et al., 2021) (Legge et al., 2012). During recall, they mentally “walk” through these loci to retrieve the stored items in order. This ancient technique (dating back to ancient Greece) leverages our strong visuospatial memory to create rich associations between the information and the imagined places. Research has demonstrated that the method of loci can significantly improve recall of word lists and other episodic memories in healthy adults, and it is famously used by memory champions to remember large amounts of data quickly and accurately (Sousa et al., 2021)

3.2.8.2. Mnemonic Devices

Mnemonic devices are strategic learning aids that help encode and retrieve information more easily by linking new information to familiar patterns, cues, or imagery (Digest #172, 2023) (Madan, 2014). They work by organizing, elaborating, or visualizing material in memorable ways, tapping into how our brains naturally store data (Digest #172, 2023). Common forms include visual images, rhymes, acronyms, and associations that make the target information more meaningful. Studies show that using mnemonic strategies can significantly boost recall; for example, training with mnemonics produces better memory performance than repetition alone (Dresler et al., 2017). By creating distinctive cues and deeper processing (e.g. a vivid image or a catchy phrase), mnemonic devices enable more efficient encoding and strengthen the ability to retrieve information later (Digest #172, 2023) (Dresler et al., 2017).

3.2.8.3. Chunking and Organization

Chunking involves breaking down a large set of information into smaller, manageable units or "chunks" to improve memory capacity (Suppawittaya & Yasri, 2021) (Norris et al., 2020). For instance, a long string of digits can be chunked into groups (like a phone number) so that each group is remembered as one unit instead of individual digits. This recoding works because short-term memory can hold only about 7±2 items, but each chunk can contain several elements, effectively increasing the amount of information retained (Norris et al., 2020). Organized chunks tap into long-term memory patterns and meaning (a process called redintegration), helping reconstruct partial memories by filling in known associations (Norris et al., 2020). Research in cognitive psychology has long shown that chunking familiar items (e.g. letters forming a word or words forming a phrase) significantly improves recall compared to ungrouped lists. By structuring information into hierarchical categories or clusters, chunking and organization reduce cognitive load and make retrieval more efficient (Norris et al., 2020)

3.2.8.4. Elaborative Rehearsal

Elaborative rehearsal is a memory technique that involves actively making connections between new information and existing knowledge to encode it more deeply (Goll, 2004) (Ways to Enhance Memory | Introduction to Psychology, 2020) Instead of merely repeating information (maintenance rehearsal), elaborative rehearsal might include thinking about the meaning of the content, forming associations, or creating examples and explanations in one's own words. This deeper processing (often aligning with the "levels of processing" theory) enriches the memory trace, facilitating the transfer of the information into long-term memory. For example, if you learn a new term, you might relate it to something you already know or use it in a sentence to provide context. Such semantic linking significantly improves recall: studies have found that people who use elaborative rehearsal (e.g. generating an image or an analogy for a concept) remember more and for longer than those who rely on rote repetition. By integrating new data with prior knowledge, elaborative rehearsal creates multiple retrieval pathways and makes the information more retrievable in the future (Ways to Enhance Memory | Introduction to Psychology, 2020)

3.2.8.5. Peg Word System

The Peg Word System is a mnemonic technique that links new information to a predetermined set of peg words—typically a rhyming list associated with numbers (e.g., one-bun, two-shoe, three-tree, etc.) (Ramlow, 2020). To memorize a list, each item is imaginatively associated with its corresponding peg word through a vivid interactive image (for example, if the first item is "milk," one might visualize a bun soaked in milk). During recall, the learner mentally goes through the peg list; each peg word cues the image and, thus, the item attached to it (Ramlow, 2020). This method provides an external structure (the rhyming pegs) that serves as a scaffold for memory, enforcing both association and order. Research shows that peg-word mnemonics can significantly improve recall of serial lists; even young children and older adults have shown better list learning with peg systems compared to no mnemonic. Because the peg words are well learned and ordered, they offer reliable retrieval cues, and the absurd or exaggerated imagery ensures the associations are memorable (Ramlow, 2020).

3.2.8.6. Keyword Method

The Keyword method is a specialized mnemonic for learning vocabulary or paired associations, often used in language learning. It involves two steps: first, choosing a keyword – a familiar word in one's native language that sounds similar to the foreign word – and second, forming a mental image that links this keyword to the meaning of the foreign word (Taheri, 2016). For example, to remember the Spanish word "pato" (which means duck), one might use the English keyword "pot" (similar sound) and imagine a duck cooking in a pot. This bizarre interactive image connects the sound of the word with its meaning. The keyword method creates a strong associative link between the new word's pronunciation and its definition, which greatly aids recall. Extensive research supports this technique: studies have found that students trained to use keyword imagery learn foreign vocabulary faster and retain it longer than those using rote memorization. Over a hundred experiments have demonstrated its effectiveness, particularly for initial learning of word meanings, by leveraging both acoustic (keyword) and visual memory cues (Taheri, 2016)

3.2.8.7. Retrieval Practice

Retrieval practice, also known as the testing effect, is the strategy of deliberately recalling information from memory (through self-testing or quizzes) to strengthen learning. Every time we actively retrieve knowledge, it solidifies that memory and makes it easier to access later (Kobayashi, 2022). Unlike simply re-reading or reviewing notes, retrieval practice forces the brain to reconstruct the memory, which enhances retention. Experiments have shown that practicing recall leads to significantly better long-term memory than additional study time – for example, students who test themselves on material remember more of it on a delayed test than students who only restudy. This effect holds true for various formats (free recall, flashcards, practice quizzes) and improves not just rote recall but also understanding and transfer of knowledge. The mechanism is thought to involve deeper encoding and feedback: each retrieval attempt highlights what is not yet mastered, guiding focused review, and also associates the context of recall with the material. In short, “use it or lose it” – actively retrieving information periodically makes forgetting less likely educational research and meta-analyses affirm that incorporating frequent low-stakes testing or self-quizzing into study routines markedly boosts learning outcomes (Kobayashi, 2022)

3.2.8.8. Dual Coding

Dual coding theory posits that we remember information better when it is encoded in both verbal and visual forms. In practice, this means combining words (or oral explanations) with pictures, diagrams, or other imagery to leverage two memory “codes” instead of one (Culatta, 2018). For example, studying a textbook diagram alongside descriptive text or creating a mental image to represent a concept from a lecture provides both a linguistic trace and a visual trace in memory. These dual codes are linked, so one can cue the other during recall. Research has consistently found that dual-coded information is more easily remembered: experiments have shown that people recall concepts better when they have seen a relevant image or visualization versus text alone. Visuals add context, meaning, and distinctiveness, especially for abstract information – by turning it into a concrete picture or spatial layout, it becomes more comprehensible and memorable (Dual Coding Theory (Culatta, 2018). In cognitive science, this is explained by the activation of separate neural pathways for imagery and language. When both pathways are engaged, memory retrieval has two routes, which increases the likelihood of successful recall.

Thus, techniques like drawing concept maps, watching educational videos, or simply imagining vivid examples while learning can significantly enhance memory through dual coding (Culatta, 2018).

3.2.8.9.Story/ Narrative Technique

The story or narrative technique involves weaving disparate pieces of information into a coherent story to aid memory. By creating a narrative that links all the items in a sequence (with events or characters representing each item), the learner leverages the natural human affinity for stories as an aid to recall (McPherson, n.d.). Stories provide context and meaningful connections between elements that would otherwise be unrelated – the narrative gives the list a logical flow and structure. For example, to remember a random list of words, one might invent a short tale where each successive word plays a part in the plot. This approach has been shown to improve recall significantly. In one study, older adults who were taught to embed word lists into a story remembered more words after delays than those who used no mnemonic (Hill et al., 1991). The narrative serves as an intrinsic cue: recalling any part of the story can cue the next part, helping retrieve the entire sequence. The more vivid and exaggerated the story, the better (since distinctive details make memories stick) (McPherson, n.d.). While creating a story can be limited by how imaginative one can be with certain information, when applicable, it exploits our strong memory for storytelling – a skill used in oral traditions and by memory experts alike to transform arbitrary items into a memorable narrative chain (Hill et al., 1991) (McPherson, n.d.).

3.2.8.10. Concept Mapping

Concept mapping is a visual organization strategy where one creates a diagram (concept map) that displays ideas as nodes and shows the relationships between them with connecting lines or arrows. By arranging information into a structured map (often hierarchical, from general concepts to specific details), learners actively organize and integrate knowledge, which enhances understanding and memory (University of North Carolina at Chapel Hill, 2025). Concept maps make abstract connections explicit – for example, a student mapping a biology chapter might draw links between terms like “cell,” “nucleus,” and “DNA,” indicating their relationships. This technique benefits memory in several ways: it encourages deep processing (deciding how concepts relate), provides a visual memory aid (the spatial layout of the map), and chunking of information into meaningful clusters. Research indicates that studying with concept maps can improve recall and long-term retention. In educational settings, students who create concept maps tend to remember material better on later tests than those who just read linear notes, especially when it comes to understanding complex interrelationships (Nicoara et al., 2020). One quasi-experimental study found that medical students who learned anatomy with concept mapping scored higher and retained information longer (even 6 months later) than those who used traditional outlines (Nicoara et al., 2020). By externalizing knowledge into a visual network, concept mapping leverages both verbal and visual memory codes (dual coding) and helps identify organizational schemas, making recall more systematic and robust (University of North Carolina at Chapel Hill, 2025) (Nicoara et al., 2020)

3.2.8.11. Aboriginal Memory Techniques

Aboriginal memory techniques refer to the traditional mnemonic practices used by Indigenous cultures, such as Australian Aboriginal peoples, which often involve storytelling, song, and connection to the landscape. One well-known technique is akin to an enriched method of loci: knowledge (e.g., tribal history, animal taxonomy) is encoded in stories and songs linked to landmarks in the natural environment (Pappas, 2021). As an elder travels across the land, each feature (rock, waterhole, etc.) cues a part of a song or story that contains the information, effectively creating a “songline” memory route. This narrative-based, multisensory approach has been passed down for generations and is remarkably effective in oral cultures for retaining vast amounts of information. Modern research suggests that incorporating Aboriginal-style storytelling with loci can enhance memory even for students trained in Western methods. In a recent experiment, medical students who learned a list of facts by embedding them in a narrative tied to local landmarks (mimicking an Aboriginal approach) performed as well as or better than those using a standard memory palace alone (Pappas, 2021) (Reser et al., 2021). In particular, the Aboriginal method led to significantly better preservation of the sequence of information, likely because the story provides a strong contextual order (Reser et al., 2021). These techniques underscore the power of combining landscape, narrative, and imagery. By making information part of a culturally meaningful story and location, memory is reinforced through multiple channels (spatial, verbal, social), achieving impressive long-term retention as demonstrated by indigenous knowledge systems (Pappas, 2021) (Reser et al., 2021)

3.2.8.12. Acronyms and Acrostics

Acronyms and acrostics use letter cues to compress information into a shorter, more memorable form. An acronym is a pronounceable word formed from the initial letters of a series of words. For example, the acronym “HOMES” is commonly taught to memorize the Great Lakes (Huron, Ontario, Michigan, Erie, Superior) (Pedersen, 2016). Instead of recalling five separate names, the learner remembers one familiar word, which cues each lake name’s first letter. An acrostic is similar but forms a phrase or sentence where each word’s first letter corresponds to the items in question. A classic acrostic for the order of planets is “My Very Educated Mother Just Sent Us Nine Pizzas,” where each word starts with M, V, E, M, J, S, U, N, P to represent Mercury through Pluto (Pedersen, 2016). These techniques work by providing a simple retrieval structure: the acronym/acrostic is easier to remember than the unorganized list, and once recalled, it unpacks into the target details. They are especially handy for remembering sequences (like biological classifications or steps in a process). In educational research, students using self-generated acronyms or acrostics often show improved recall of factual lists. One study on learning a procedural task found that a mnemonic acronym significantly boosted performance and made the knowledge more resistant to interruptions compared to no mnemonic. By relying on familiar language patterns and chunking multiple items into one cue, acronyms and acrostics reduce memory load and help prevent forgetting of arbitrary information (Pedersen, 2016).

3.2.8.13. Rhymes and Songs

Using rhymes and songs is a powerful memory aid rooted in our capacity to remember patterned, musical information. Rhymes impose a catchy rhythm and sound structure on information, making it stickier – for instance, the rhyme “ ’i’ before ‘e’ except after ‘c’ ” helps recall an English spelling rule. Songs add melody and often a familiar tune, which provides a scaffold for recall. A well-known example is how children learn the alphabet by singing the “ABC” song, which turns 26 unrelated letters into a memorable melody (Pedersen, 2016). The combination of melody, rhyme, and rhythm creates multiple reinforcement cues (auditory patterns, beat, and often emotional engagement) that significantly improve retention. Research supports that setting information to music can enhance learning for adults as well. One study found that adults memorized foreign language phrases more easily when they were sung rather than spoken (Pedersen, 2016). Similarly, patients with dementia have shown better recall of information and improved mood when engaged in singing familiar songs, indicating that musical memory pathways remain robust. Rhymes work by exploiting phonological memory – the end sounds and cadence act as triggers for the next line. Because music and rhymes activate different memory systems (procedural/musical memory in addition to declarative), they provide an alternative route to the stored information. In essence, information set to a rhyme or tune is "packaged" in a way the brain finds naturally easy to retrieve, often with a ~30% or more improvement in recall observed in experimental settings compared to plain text (Pedersen, 2016).

3.2.8.14. Name Face Association

Remembering people's names can be improved by the name-face association technique, which entails linking a person's name to a distinctive visual feature of their face through a creative image. The method typically involves three steps: (1) identify a prominent facial feature (e.g., a person has a big nose), (2) think of a concrete word or phrase that sounds like the person's name (this becomes the "keyword"), and (3) concoct a vivid, even absurd, mental image involving that facial feature and the keyword (McPherson, n.d.). For example, if you meet someone named "Conrad" with a large nose, you might use the keyword "con (convict) riding a rad (rat)" and imagine a tiny convict riding a rat down the bridge of Conrad's nose. The next time you see that person's face, the unique facial feature (his nose) will cue the bizarre image of a convict and rat, which in turn cues the sound "Con-rad," jogging your memory of his name (McPherson, n.d.). This technique capitalizes on the distinctiveness of exaggerated imagery and the fact that visual memory for faces is quite strong – by attaching an additional layer (the name clue) to the face, recall is improved. Empirical studies have shown significant benefits: when subjects are trained in a face-name mnemonic like this, their ability to recall names improves markedly across all age groups (Yesavage & Rose, 1984). Even older adults, who often struggle with name recall, demonstrate memory gains after learning the association strategy (Yesavage & Rose, 1984). The key is that the stranger and more striking the associative image, the more likely it is to stick, making the once-arbitrary name memorable by virtue of a funny mental picture attached to the person's face (McPherson, n.d.)

3.2.8.15. Association (Bizarre Visual Imagery)

The basic association involves linking new information with something already known or with another mental cue, but the use of bizarre visual imagery takes this to the next level by making the association as wild and unusual as possible. The human memory has a bias for the extraordinary – unusual or absurd images tend to be remembered better than mundane ones (a phenomenon known as the bizarreness effect). Thus, when trying to remember an item or a fact, concocting a bizarre mental image that associates it with a familiar reference can make it far more memorable (Pedersen, 2016). For example, to recall that Isaac Newton discovered gravity, you might imagine Newton juggling planets or getting hit by an apple the size of a car. The absurdity (planets and giant apple) ensures the scene is distinctive in your mind. Likewise, if you have to remember to buy eggs and shampoo, you might picture a chicken laying eggs into a shampoo bottle – it's silly, but that's exactly why you'll remember it. By associating the items in a single exaggerated image, you create a memorable link. Psychological research supports the effectiveness of bizarre imagery: information encoded with bizarre or humorous images is often recalled more accurately than information encoded with normal images, provided the bizarre image distinctly stands out in context (Pedersen, 2016). The technique works best when the imagery is highly visual, vivid, and involves multiple elements interacting in an unlikely way. The mental effort to create such an image also means deeper processing, which further enhances memory. In summary, forging an association – especially a quirky, vivid one – between new information and an existing memory or concept makes the new information more distinctive and easier to retrieve later (Pedersen, 2016)

3.2.8.16. Spaced Repetition

Spaced repetition is a learning technique where study sessions or reviews are spaced out over time rather than crammed in one sitting in order to exploit the way human memory works. After initial learning, information is reviewed at increasing intervals (for example, one day later, then three days, then a week, etc.) to reinforce the memory just as it's about to be forgotten (Birmingham City University, n.d.). This approach counters the "forgetting curve" – the natural decline of memory retention – by refreshing the memory periodically, which strengthens and prolongs retention. Research has consistently found that spaced repetition yields significantly better long-term recall than massed practice (cramming). One classic finding is that if you study something twice, spacing those two study episodes apart (even by days or weeks) results in more durable memory than studying it twice back-to-back (Birmingham City University, n.d.). Spaced repetition essentially gives the brain multiple opportunities to encode the information, and the slight forgetting that happens between sessions means you have to work a bit to retrieve it, which further consolidates the memory (Goll, 2004) (similar to retrieval practice). In practical terms, this is the principle behind flashcard systems like Anki or the Leitner system, which schedule reviews at optimal intervals. By the time you reach the exam (or need the information), spaced practice ensures the memory has been cemented in long-term storage. Cognitive psychologists have documented that spaced learning can improve recall by 20-50% or more compared to single-session learning. Thus, instead of one marathon study session, breaking material into short, spaced sessions (with sleep in between, ideally) is a proven strategy for stronger, more efficient memory retention (Birmingham City University, n.d.).

3.2.8.17. Visualization and Imagery

Using visualization and mental imagery means actively creating pictures in your mind to represent the information you want to remember (Madan, 2014). Rather than relying only on verbal or rote methods, you form a visual scene or symbol that encodes the idea. Our brains have a powerful capacity for visual memory – often, we can recall images or spatial layouts more readily than abstract facts. By harnessing that, imagery techniques make memories more concrete. For example, if you need to remember a person’s name (Mr. Baker) and profession, you might imagine that person baking bread (visualizing them as a “baker” with a chef’s hat). Or, to memorize a historical date, you could picture the numerals as objects (imagine the year 1776 as two sevens wielding swords and declaring independence). The effectiveness of imagery is well-supported by research: studies in cognitive psychology have shown that when people create vivid mental images for information (like forming a mental image for each word in a list), their recall is significantly better than those who repeat the words without imagery (Marre et al., 2021) (Pearson et al., 2015). Visual imagery provides a second code (as per dual coding theory) and often engages emotion or absurdity (if the image is funny or strange), making the memory stand out. The more detailed and vivid the image, and the more senses involved (visualizing not just appearance but perhaps sound, touch, etc.), the stronger the memory tends to become (Nanay, 2021). Brain imaging research even shows that imagining something activates similar brain areas as actually perceiving it, suggesting mental images can embed information in memory in a perception-like way (Pearson et al., 2015). In practice, whether it’s the method of loci, the keyword method, or just solo visualization, imagery is a core component of many successful memory techniques because it taps into the mind's natural picture memory system to boost recall (Pearson et al., 2015)

3.2.8.18. Physical Activity and Sleep

Beyond cognitive techniques, certain lifestyle factors like regular physical exercise and adequate sleep profoundly affect memory function. Physical activity, especially aerobic exercise, has been linked to improved memory and overall brain health (Stern & Alberini, 2013). Exercise increases blood flow to the brain and stimulates the release of growth factors that promote neuroplasticity and the growth of new neurons (particularly in the hippocampus, a key memory center) (Latino & Tafuri, 2024). Studies have shown that consistent aerobic exercise can enhance memory performance in both younger and older adults. Meta-analyses of clinical trials report that sedentary adults who begin exercising see significant improvements in memory tests compared to control groups, with exercise interventions yielding large effect sizes for memory enhancement (Hoffmann et al., 2021). Essentially, what's good for the heart is good for the brain: physical activity helps slow age-related cognitive decline and makes the brain's memory networks more efficient. Equally important is sleep. Sleep is when our brains consolidate memories – transferring short-term traces into more durable long-term storage. Getting quality sleep after learning is known to improve recall, as the brain replays and strengthens neural connections formed during the day. In experiments, people who sleep soon after studying remember material better the next day than those who stay awake for an equivalent period (Potkin & Bunney, 2012). Even a single night of sleep can produce a measurable boost in memory consolidation for newly learned information (Potkin & Bunney, 2012). Deep slow-wave sleep and REM sleep both play roles in processing different types of memories (e.g. facts vs. procedural skills). Therefore, maintaining good sleep hygiene (adequate duration and consistent sleep schedules) and staying physically active are practical, evidence-based ways to support and enhance one's memory. They create an optimal biological environment for all the other memory techniques to work more effectively.

3.2.8.19. Nootropics

Nootropics, often called "smart drugs" or cognitive enhancers, are substances (pharmaceuticals, supplements, or herbal extracts) that claim to improve cognitive functions such as memory, focus, or creativity (Madan, 2014). Examples include prescription stimulants (like modafinil or methylphenidate), compounds like piracetam (the original “nootropic” described in the 1970s), caffeine, and herbal supplements like Ginkgo biloba and Bacopa monnieri (Malík & Tlustoš, 2022). These substances work through various mechanisms – some increase neurotransmitter levels, and others improve blood flow or energy metabolism in the brain – with the goal of enhancing synaptic plasticity and memory formation (Malík & Tlustoš, 2022). Research on nootropics shows mixed but intriguing results. Certain drugs clearly help memory in clinical populations (e.g. donepezil can improve memory in Alzheimer’s disease, and stimulants can aid attention and working memory in ADHD). In healthy individuals, nootropics tend to have more modest effects. For instance, caffeine and modafinil can improve alertness and reduce fatigue, indirectly benefiting memory tasks that require concentration. Some studies on over-the-counter supplements report slight improvements in memory – Bacopa monnieri, an Ayurvedic herb, has shown some memory benefits in trials after weeks of use (Lorca et al., 2023). Overall, while nootropic substances can enhance memory performance (especially if one has deficiencies or is sleep-deprived), their effects are often limited in a well-rested, healthy brain (Malík & Tlustoš, 2022). They are best viewed as an adjunct; for example, a student might find that a cup of coffee before studying helps them stay focused and encode memories better. It’s important to note that nootropics can carry side effects (jitters, insomnia, etc.) and ethical considerations, and none provide a magic bullet for memory. Current evidence suggests that the most benefit is seen in individuals with cognitive impairment or fatigue, whereas in average adults, improvements in memory from nootropics are modest and vary by individual (Malík & Tlustoš, 2022). As research continues, some new compounds may offer safer or more robust memory enhancement, but experts generally emphasize that proper sleep, exercise, and proven strategies (like those above) should remain the foundation for boosting memory.

3.2.9. Summary

While traditional memory enhancement techniques discussed above are among the most widely recognized, they represent only a subset of the myriad strategies available for improving memory. Countless other methods contribute to cognitive enhancement. This research focuses explicitly on applying the method of Loci to integrate emerging technologies. In the upcoming sections, I will discuss in greater detail both the reasons for its selection over other strategies and its practical application.

3.2.10. Classification of Memory Techniques and Relevance

Memory enhancement techniques vary in their mechanisms, applications, and effectiveness across different contexts. The table below provides an overview of these techniques, outlining their descriptions, best use cases, and potential relevance to this thesis work.

Memory Technique	Description	Best Use Cases	Relevance to Thesis
Method of Loci	Uses spatial locations to encode information by associating it with familiar places.	Spatial learning, historical facts, events, locations, navigation, and studying subjects requiring sequence retention.	Highly relevant - AI-generated cues and AR overlays can enhance spatial memory.
Mnemonic Devices	Memory aids that structure information in a memorable way using patterns, cues, or imagery.	Memorizing lists, learning new terms, and improving recall speed.	Moderate - AI might automate mnemonic creation; AR could visualize mnemonics.
Chunking and Organization	Breaking information into smaller, meaningful units to improve retention.	Organizing large sets of information, improving working memory, and studying complex topics.	Low - AI might assist chunking, but AR has minimal impact.

Table 1: Memory Enhancement Techniques – Descriptions, Use Cases, and Relevance 1

Memory Technique	Description	Best Use Cases	Relevance to Thesis
Elaborative Rehearsal	Connecting new information to prior knowledge for deeper encoding.	Deep learning of concepts, improving comprehension and long-term retention.	Moderate - AI could generate connections, but AR is less impactful.
Peg Word System	Associating words with numbers in a fixed list and linking them using imagery.	Memorizing ordered lists, recall of numerical data, and remembering structured information.	Low - Mainly a linguistic tool, AR application is minimal.
Keyword Method	Using a sound-alike word to link new information with existing knowledge through imagery.	Learning foreign vocabulary, improving associative learning.	Moderate - AI can assist with keyword generation, but AR has limited use.
Retrieval Practice	Actively recalling information through self-testing to strengthen memory.	Exam preparation, strengthening retention over time.	Moderate - AI-based testing could automate spaced retrieval.
Dual Coding (Visual-Verbal)	Encoding information in both verbal and visual forms to enhance recall.	Visual and verbal learners, conceptual subjects, educational settings.	High - AR can visually present dual-coded material in real-world contexts.

Table 2: Memory Enhancement Techniques – Descriptions, Use Cases, and Relevance 2

Memory Technique	Description	Best Use Cases	Relevance to Thesis
Story/Narrative Technique	Embedding information within a narrative to improve retention.	Learning sequences of historical events, improving storytelling memory.	High - AI-generated stories with AR-enhanced visuals could support learning.
Concept Mapping	Visually organizing knowledge into structured maps showing relationships.	Complex subjects with interrelated concepts, organizing large knowledge areas.	Moderate - AI can generate concept maps; AR can visualize them.
Aboriginal Memory Techniques	Indigenous memory techniques that use landscape-based and oral storytelling mnemonics.	Oral traditions, long-term knowledge retention, cultural memory preservation.	High - AI can digitize and enhance Indigenous storytelling; AR can overlay landmarks.
Acronyms and Acrostics	Using acronyms or acrostics to compress information into an easy-to-recall format.	Memorizing structured information acronyms for professional knowledge.	Low - Limited AI or AR application.

Table 3: Memory Enhancement Techniques – Descriptions, Use Cases, and Relevance 3

Memory Technique	Description	Best Use Cases	Relevance to Thesis
Rhymes and Songs	Encoding information with rhythmic patterns or melodies to improve recall.	Language acquisition, early education, memorizing poetry or formulae.	Moderate - AI-generated songs/rhymes might aid memory, but AR is less relevant.
Name-Face Association	Linking names to facial features using memorable visual cues.	Remembering names and personal details in social and professional settings.	Moderate - AI-generated associations might help, but AR is less applicable.
Association (Bizarre Visual Imagery)	Creating vivid and bizarre visual associations to strengthen memory connections.	Enhancing associative recall, improving retention through exaggerated imagery.	Moderate - AI can assist with imagery generation, and AR may provide interactive cues.
Spaced Repetition	Reviewing information at spaced intervals to reinforce long-term retention.	Studying over long periods improves recall efficiency.	High - AI-driven spaced repetition tools could integrate with AR reminders.

Table 4: Memory Enhancement Techniques – Descriptions, Use Cases, and Relevance 4

Memory Technique	Description	Best Use Cases	Relevance to Thesis
Visualization and Imagery	Forming mental images to represent abstract concepts or facts.	Abstract concepts, subjects requiring visual representation, spatial learning.	High - AI-generated imagery and AR overlays could enhance visualization techniques.
Physical Activity and Sleep	Exercise and sleep improve brain plasticity, consolidation, and cognitive function.	Overall brain health, reducing cognitive decline, improving memory consolidation.	Low - Important for cognitive function but outside the scope of AI/AR.
Nootropics	Substances or supplements that may enhance cognitive function and memory.	Short-term cognitive enhancement, supplementing natural memory capacity.	Low - AI-based cognitive enhancement tools exist, but AR is minimally relevant.

Table 5: Memory Enhancement Techniques – Descriptions, Use Cases, and Relevance 5

In summary, the table above emphasizes the diverse mechanisms and contexts in which memory enhancement strategies operate, from classical mnemonic devices to lifestyle interventions like exercise and sleep. Techniques such as the Method of Loci stand out in their potential for integration with emerging technologies, particularly AI and AR, due to their strong reliance on spatial and visual elements. In fact, the Method of Loci overlaps with key concepts from many other techniques (e.g., dual coding, associative imagery), making it a focal point for deeper exploration in upcoming sections.

3.3. Method of Loci and Memory Palace

The Method of Loci, or memory palace technique, originated in ancient Greece ("Memories," 2013) and harnesses familiar environments for organizing information. A famous legend credits the poet Simonides of Ceos with discovering it after identifying guests' seating positions in a collapsed hall (Heerema, 2024). By mentally placing memorable images at distinct "loci" along a path, one can recall items systematically. This approach exploits spatial memory to store vast amounts of data with minimal confusion. It remains widely used—from memorizing speeches to advanced academic fields—and yields robust recall. By "walking" the route, individuals retrieve each piece of information in proper sequence.

The effectiveness of the Method of Loci is primarily due to its reliance on spatial memory--a cognitive system that is naturally strong and highly developed in humans (Legge et al., 2012). Spatial memory allows individuals to remember locations vividly, even when other cognitive resources are depleted. By leveraging this natural capacity, the Method of Loci enhances short-term and long-term memory retention.

This technique has been applied in various settings, from memorizing speeches to academic learning. For instance, students studying complex fields like endocrinology--the study of hormones and the regulation of bodily processes--have experienced significant improvements in performance after using the Method of Loci to recall critical details (Legge et al., 2012). Researchers have demonstrated that this technique is especially beneficial for tasks requiring extensive information recall.

However, while the Method of Loci is highly effective, it demands considerable cognitive effort. Creating and maintaining detailed mental environments for large volumes of information can be taxing, potentially limiting the practicality of the technique for some users. The mental effort required to construct and manage the vivid mental images necessary for recalling information can present difficulties, mainly when applied to larger, more complex data sets.

3.3.1. Design and Construction of Memory Palaces

Below is a concise, step-by-step guide on how to construct and use a memory palace, offering practical instructions for anyone looking to apply the method of loci to their learning or recall strategies.

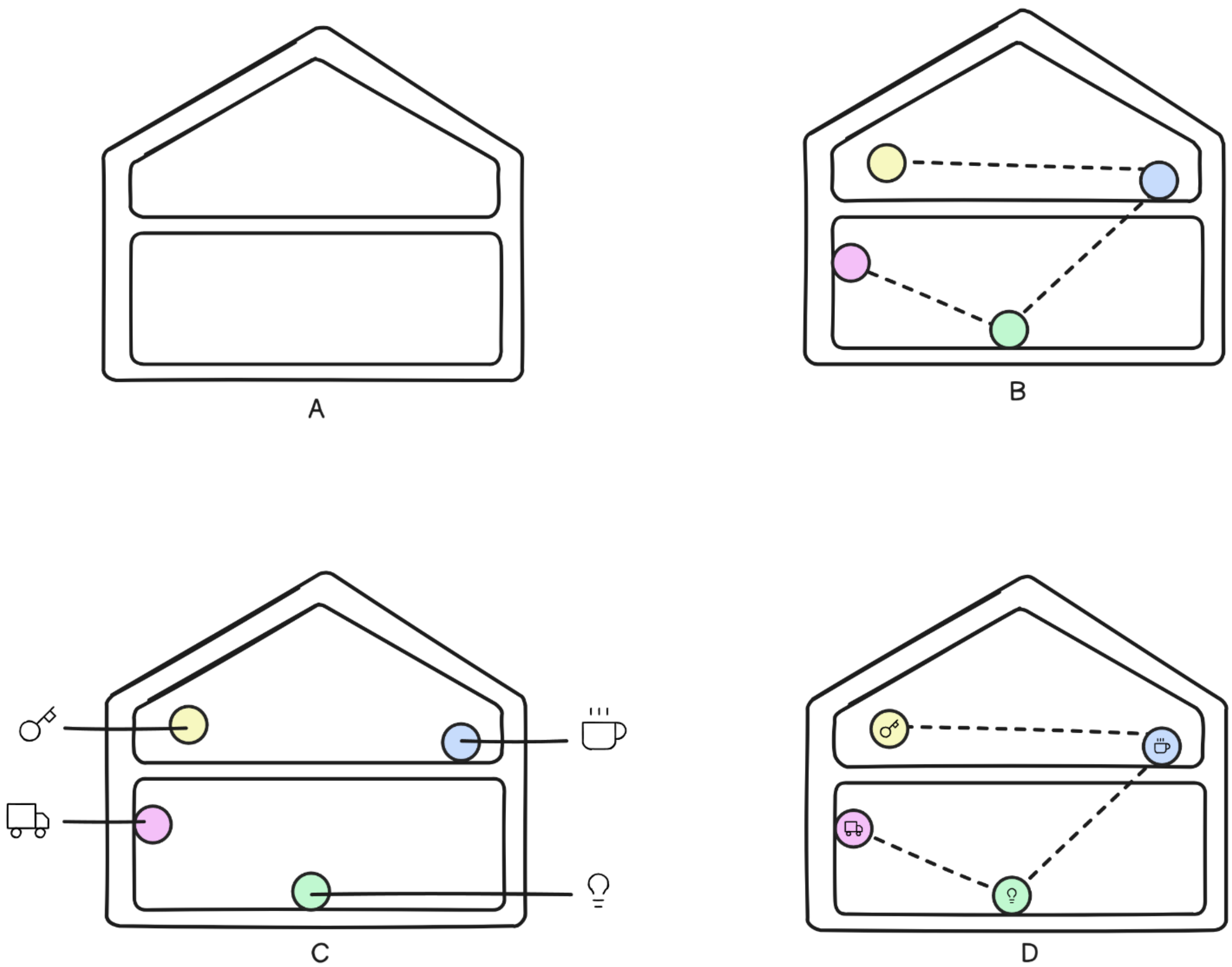

Figure 5: Construction of Memory Palace - (adapted from Sousa et al., 2021)

A: Begin by selecting a familiar space like your home or a regular route to serve as your memory palace. B: Map out a fixed path within this space, designating distinct stops as loci for each item you want to remember. C: As you mentally traverse your route, assign vivid and memorable associations to each stop in the order of your list. D: Finally, retrace your path to recall each item sequentially. (adapted from Sousa et al., 2021)

1. **Choose a Familiar Location:** Select a place you know intimately (e.g. your home, school, or office). You should be able to vividly picture this environment and navigate it in your mind with ease (How to Build a Memory Palace, 2023) (Dietrich Arts & Sciences Undergraduate Studies, 2025). This will form the backdrop of your memory palace, leveraging your brain's strong spatial memory.

2. **Define a Path and Loci:** Plan a specific route through the location and identify distinct loci (fixed spots or landmarks) along that path (How to Build a Memory Palace, 2023). For example, if using your home, you might start at the front door, then move to the entryway table, the living room sofa, the kitchen sink, etc. Number these locations in a logical sequence (many prefer a clockwise or consistent order) so you have an established journey with no dead-ends. Each locus will serve as a "container" for a memory (Dietrich Arts & Sciences Undergraduate Studies, 2025).
3. **Associate Items with Vivid Images:** Take the information you want to memorize and create a vivid, unusual mental image for each item. Place each image at a locus on your route. The more exaggerated, sensory, and imaginative the imagery, the more it will stick in your mind (How to Build a Memory Palace, 2023). For example, if you need to remember to buy carrots, you might envision giant carrots knocking on your front door (first locus). Make the images interact with the surroundings in a distinctive way – use bizarre or funny scenarios, rich colors, sounds, and even smells, as our brains remember novel visuals strongly (How to Build a Memory Palace, 2023). Each locus should host one or a manageable chunk of information.
4. **Embed and Rehearse the Journey:** Once your items are placed, mentally walk through your memory palace to encode the sequence. Start at the first location and vividly see the image you planted there, then move to the next locus and so on (Dietrich Arts & Sciences Undergraduate Studies, 2025). On your first few runs, really focus on each exaggerated scene to cement it. Repeat this "memory walk" along the exact same route, in the same order, until you can effortlessly recall each item (How to Build a Memory Palace, 2023). For added mastery, practice jumping to loci out of order or even traversing the route backward – this ensures you've robustly linked each location with its associated item. After this, whenever you need to retrieve the information, you simply imagine walking through those familiar places; each locus will trigger the memory you stored there (Dietrich Arts & Sciences Undergraduate Studies, 2025).

By following these steps, one can construct a reliable memory palace. In essence, you're building a mental "map" where each stop on the map holds a specific memory – an approach that exploits our strong spatial memory skills to improve recall.

3.3.2. Applications in Real-World Contexts

The method of loci has diverse applications across educational, competitive, professional, and cognitive training domains. By utilizing spatial memory, it helps people handle large amounts of information more efficiently. Key real-world contexts include (not limited to):

- Education and Learning: Students in fields like medicine and law use memory palaces to remember large amounts of information, resulting in higher exam scores than traditional study methods (Qureshi et al., 2014).
- Competitive Memory Championships: Top memory athletes use loci-based techniques to memorize decks of cards, random digits, or words at high speed, setting impressive world records (Dresler et al., 2017).
- Professional and Everyday Use: From speech memorization to client name recall, the Method of Loci aids orators, actors, teachers, businesspeople, and anyone needing structured recall (Legge et al., 2012).
- Cognitive Training: It serves as a “brain exercise” to maintain cognitive health in older adults, with some therapeutic usage for conditions like mild cognitive impairment (Dresler et al., 2017).

3.3.3. Memory Champions: Strategies, Training and Success Stories

World-class memory athletes consistently credit the method of loci as a foundational strategy, often enhanced with additional mnemonic systems. These champions train intensively to push the limits of human memory, and their success stories offer insight into effective techniques:

Almost all memory champions use memory palaces in some form, typically combined with a system to convert raw data (numbers, cards, words) into vivid images. This allows speed and efficiency in placing those images into loci. For example, to memorize numbers, competitors often use phonetic or person-action systems to translate digits into images, which are then deposited in a memory journey (Kermode, 2023). By pre-learning a code (such as the Major System or Dominic System), they can encode a group of digits as one image in a split second. The method of loci then provides an organized “storage space” for these images. During recall, they simply traverse the mental route and decode the images back into the original information. This structured approach drastically amplifies how much data one can remember in order. As one champion put it, without such a technique, “You might see a random row of digits, but I’m seeing a ‘tree’ or a ‘cat’ at each location – I wouldn’t remember the sequence without some sort of method” (Kermode, 2023). The training of memory athletes involves building dozens of these palaces and practicing until placement and retrieval become automatic.

Katie Kermode, one of the world’s top memory athletes (with multiple world records), provides a striking example of these methods in action. Kermode holds the record for memorizing 1,080 random digits in 30 minutes (Kermode, 2023). She achieves such feats by using a personalized version of the method of loci. For memorizing numbers, Kermode uses the “Ben System” (a sophisticated variation of the Major System) to encode every three-digit combination from 000 to 999 into a unique image or person. This means she has a mental image ready for any three-digit chunk (for instance, 693 becomes a theatrical showman in her mind, and 522 becomes an image of red lentils spilling everywhere) (Kermode, 2023). When competing in a numbers event, she breaks the long sequence into groups of three digits and places each image into a locus in one of her memory palaces in order. Later, she walks back through that palace in her mind to recall each trio and reads off the digits. Kermode started training in 2008 and soon set a record by memorizing 84 names and faces in 5 minutes. Notably, she says she wasn’t born with an exceptional memory. As a child she enjoyed memorizing things like license plates for fun, but only through deliberate training did she reach world-class performance. Her story illustrates how a systematic approach (imagery + loci) and practice can yield astounding results. She also emphasizes creativity in making images (“the more outlandish, the better”) and focus during recall while noting that some events (like names) still challenge even top competitors (Kermode, 2023).

Memory champions often train for years, treating it like a sport. They accumulate hundreds of memory palaces for different purposes (some palaces reserved for numbers, some for words, etc.) and drill regularly to increase speed and accuracy. A champion like Dominic O’Brien, for example, developed his own number encoding (the Dominic System) and used it alongside the loci method to win the World Memory Championship eight times. He famously memorized the order of 54 shuffled decks of cards after a single sighting each – an achievement made possible by linking card images in long memory journeys. Another elite memorizer, Alex Mullen (a three-time world champion), has described how integrating evidence-based learning techniques like spaced repetition with his library of memory palaces helped him retain vast amounts of medical knowledge during school (Memory Palace Database - Memory Techniques and Memory

Palaces for Students, 2019). Mullen and others share tips such as ensuring loci are distinct and memorable (to avoid confusion), practicing visualization clarity, and optimizing review schedules of palaces to transfer short-term contest memories into long-term store. Many champions also highlight the importance of mental fitness and balance. They practice visualization like a muscle, often intermixing it with meditation or other focus training. The common thread in all these success stories is that the method of loci is the key framework; it's the canvas upon which all other mnemonic tricks are applied. With enough training, champions demonstrate feats like recalling a deck of cards in under 15 seconds or thousands of binary digits in minutes, emphasizing the power of this technique when expertly applied.

3.3.4. Technological Enhancements and Digital Adaptations

Modern technology has sought to augment and simplify the method of loci, bringing memory palaces into virtual and digital realms. From virtual reality experiences to smartphone apps, these adaptations aim to leverage computers and graphics to help users create and use memory palaces more effectively. The table below summarizes key technological adaptations, their features, and findings on their effectiveness:

Tool	Features	Effectiveness
VR Memory Palaces	Immersive 3D environments to simulate walking through a palace	Up to 20-25% higher recall compared to non-immersive methods (Dresler et al., 2017).
AR-Based Apps (e.g., HoloLens "Loci")	Overlay digital objects onto real surroundings as memory anchors	Encourages easier visual association and retention, though limited large-scale studies (Qureshi et al., 2014).

Table 6: Key Technological Adaptations 1

Tool	Features	Effectiveness
Gamified Mobile/PC Apps (e.g., memoryOS)	Pre-made 3D palaces, tutorials, spaced repetition training	Users report ~70% improved recall, suggesting strong potential for sustainable learning (Dresler et al., 2017).

Table 7: Key Technological Adaptations 2

These technologies lower barriers to entry by automating some steps of the Method of Loci, offering interactive tutorials, and making practice more engaging (Qureshi et al., 2014).

3.3.5. Evaluating Efficacy: Empirical Studies and Outcomes

The method of loci is one of the most extensively studied mnemonic strategies, consistently shown to boost recall. Since the 1960s, controlled experiments have found that participants memorizing word lists via a memory palace often remember significantly more items than those relying on simple repetition. In one classic demonstration, more than half the subjects could recall at least 18 items out of a 20-word list—far surpassing participants without mnemonics (Bellezza, 1981). Such results have been replicated across many studies, emphasizing the technique's enduring utility (Qureshi et al., 2014).

A primary reason for its effectiveness is its emphasis on elaborate encoding. Instead of passively rehearsing, learners create vivid mental images tied to well-known locations, forming multiple cues for later retrieval. Researchers note that mnemonics like loci "impose meaning and structure" onto material that might otherwise be disjointed (Qureshi et al., 2014). This approach demands more initial effort than rote memorization, but it generally produces greater long-term retention and resilience against interference.

In educational settings, students instructed in memory palaces often outperform peers on exams. One study in medical education showed that students who constructed memory palaces for course content earned significantly higher test scores and reported the technique improved their comprehension (Qureshi et al., 2014). Another investigation revealed that learners practicing loci with real campus locations not only boosted immediate recall but continued applying the strategy long after the study ended (Heerema, 2024). Although beginners may need guidance to develop effective imagery and location selection, even short practice sessions have yielded substantial gains.

Neuroscientific research supports these observations. A study of memory “athletes” found most relied on loci as their main strategy; brain scans showed heightened activity in regions associated with spatial navigation (Qureshi et al., 2014). Another investigation with ordinary adults demonstrated that six weeks of daily loci training more than doubled their ability to recall word lists—from around 26 items to 62 out of 72 (Cell Press, 2017). Follow-up tests four months later revealed they maintained much of this improvement without additional practice. Imaging data further indicated that these new skills stemmed from changes in functional connectivity, resembling the brains of memory champions (Cell Press, 2017).

When compared to other mnemonic techniques, such as acronyms or short-term repetition exercises, the method of loci often yields superior results—particularly for larger amounts of information or ordered lists (Cell Press, 2017). However, it may be cumbersome for extremely simple tasks, and visualization challenges or severe cognitive impairments can limit its effectiveness (Sousa et al., 2021). Overall, abundant evidence from psychology labs and brain-imaging studies confirms that the method of loci offers a durable, powerful way to expand memory capacity.

3.4.Technological advancements in Memory Augmentation

Technological innovations have significantly advanced the field of memory augmentation. Among these, Virtual Reality (VR) and Augmented Reality (AR) have emerged as powerful tools for enhancing cognitive functions, particularly memory. Integrating Artificial Intelligence (AI) with AR has opened new avenues for personalized and context-aware memory support systems.

3.4.1. Current and Emerging Technologies for Memory Support

Modern technology is increasingly used to bolster human memory. Wearable devices and software tools are being developed to function as "cognitive prosthetics" that aid recall and retention. For example, experimental smart glasses and mobile apps can capture information from a user's environment and later present context-aware reminders (DeVaul, 2003). One recent system, Memoro, is a wearable audio device that uses AI to record and retrieve conversations, delivering timely memory cues with minimal user effort (Zulfikar et al., 2024). In a user study, Memoro's AI-driven prompts significantly improved users' recall confidence while reducing the need to manually check notes beyond wearables; traditional memory aids like digital notepads and calendar apps are evolving with AI integration to become more proactive and context-sensitive, behaving like virtual assistants that remind users at the right place and time rather than just on a schedule (DeVaul, 2003).

3.4.2. Artificial Intelligence in Memory Support

Artificial intelligence is central to modern memory augmentation, personalizing recall support by learning users' habits and offering just-in-time reminders or cues. Systems like Memoro (Zulfikar et al., 2024) interpret context and queries in real-time, proactively feeding hints when someone struggles to remember. AI also automates mnemonic creation—turning abstract concepts into vivid images or stories—and assists with knowledge retrieval, sifting through personal archives (emails, photos, messages) to surface relevant details on demand. This combination of context-awareness and proactive assistance helps users recall information more confidently and reduces cognitive load, eliminating the need to pause conversations or tasks to look things up.

In learning contexts, AI-driven spaced repetition can adapt review schedules to each individual, focusing on weaker areas and tailoring materials to different learning styles (Belkacem et al., 2020). Projects like ExoMem and research by Makhataeva and team (Makhataeva et al., 2023) further illustrate how AI offloads memory tasks, such as remembering where items are placed or reminding users of appointments via AR cues, while continuously observing interactions and adjusting prompts. Ultimately, the goal is a symbiotic relationship between human memory and AI, allowing people to stay cognitively engaged as the AI handles routine memory tasks in the background.

3.4.3. Virtual Reality (VR) and Augmented Reality (AR) in Memory Augmentation

Virtual Reality (VR) and Augmented Reality (AR) technologies offer immersive ways to enhance memory, notably through the “memory palace” (Method of Loci). VR can be implemented for this approach by providing controllable 3D environments for users to navigate and store information. In a 2022 experiment, participants who used a VR memory palace recalled about 20% more than those using traditional methods, with over 22% improvement on a second trial (Moll & Sykes, 2023). Researchers attribute these gains to VR’s ability to harness spatial memory, simulate realistic navigation, and make memorization feel more like a game, leading to greater motivation and confidence (Moll & Sykes, 2023).

Beyond the memory palace, VR and AR can also bolster episodic memory (remembering events in context). In one study, participants explored a virtual museum tour: those who walked in an AR setup outperformed users in a stationary VR environment (Pastor & Bourdin-Kreitz, 2024), highlighting how physical movement and real-world cues can enhance memory encoding. AR similarly shows promise for prospective memory by providing location-based reminders, for instance, a digital note appearing only when you look at your fridge. Comparisons between AR and VR suggest that AR can reduce mental load by anchoring information to real objects. Though careful design is crucial, overly cluttered visuals or frequent pop-ups can overwhelm users and diminish benefits (Buchner et al., 2021). Overall, with thoughtful implementation, AR/VR can offer powerful, accessible tools for diverse memory tasks.

3.4.4. AI and MR Integration for Enhanced Memory Support

Combining AI with mixed reality (MR), which includes AR and VR, opens up interactive memory augmentation experiences that are more powerful than either technology alone. AI and MR complement each other: AI can handle understanding context, personalizing content, and making intelligent decisions, while MR provides an immersive interface to deliver the AI's assistance in a natural way. In an integrated system, AI might analyze a user's environment (via computer vision) and their schedule or behaviour patterns, and then MR can overlay just-in-time memory cues within the user's real or virtual field of view. This creates a kind of feedback loop for cognitive augmentation: the AI continuously interprets what the user might need (e.g., "Alice seems to not recognize the person in front of her"), and the MR interface immediately presents the relevant memory aid (e.g., a floating label with that person's name and context of where they met before).

ExoMem (Extended Memory) exemplifies AI+MR integration by using AR glasses and AI to externalize memory. In a demonstration at Nazarbayev University, users wearing the system found virtual objects and notes placed in real-world locations, e.g., a virtual key on a table where they needed to remember a real key (Makhataeva et al., 2023). The AI "sees" through the camera, tracks the user's to-do list, and overlays contextually relevant cues, creating a real-world "memory palace." Evaluations showed these AR prompts helped users recall tasks without causing excessive cognitive load (Makhataeva et al., 2023). The system adapts prompts based on user feedback, reducing notifications if someone is annoyed, for instance, and is designed as assistive technology for individuals with memory impairments. Another AI+MR approach features conversational agents (like a virtual Siri) within AR: they answer questions, proactively offer memory support, and highlight items in a grocery store or remind you of people's names. Early prototypes at MIT demonstrate real-time factual reminders or corrections via AR text bubbles, illustrating how these assistants embody "situated intelligence" that unobtrusively augments cognitive functions (DeVaul, 2003).

3.5. Thematic analysis of AI and AR applications in Memory Augmentation

A review of the extensive literature on AI and AR applications for memory augmentation reveals a wide range of intriguing insights and approaches. A subsequent thematic analysis was conducted to organize this diversity and draw meaningful connections, resulting in the distillation of these insights into cohesive themes. This method proved essential for synthesizing current knowledge, identifying patterns, and highlighting points where existing research converges or diverges. By employing this analysis, a structured perspective emerged on how AI and AR can influence cognitive processes in memory augmentation, guiding the exploration of underlying themes that drive this technology's transformative potential.

3.5.1. Personalization and Context Awareness

One of the most significant themes in applying AI and AR to memory enhancement is their capacity to provide personalized, context-aware support. AI algorithms analyze user behaviour, learning preferences, and environmental factors to tailor memory aids in real time. For instance, in systems like ExoMem, AI generates visual cues and adapts them based on how the user interacts with their surroundings. This context awareness enhances memory retention by aligning information with familiar, real-world contexts (Makhataeva et al., 2023). Personalization ensures that users receive memory prompts that are meaningful to them, optimizing the efficiency of recall processes.

By adapting cues to each user's unique cognitive patterns, these systems go beyond generalized memory strategies, offering targeted interventions that enhance memory where users need it most. The use of AI to fine-tune memory aids in real time demonstrates the potential of these technologies to act as cognitive assistants, continuously learning from and adjusting to individual users (Fischer, 2023).

3.5.2. Interactive Learning Environments

Another key theme is the role of AI and AR in creating interactive learning environments. These systems engage users actively rather than passively, fostering deeper cognitive engagement.

For example, AI-powered characters in AR environments, like Wol, create opportunities for interactive learning by responding to user input in real time (Inworld, 2024). These characters are more than static sources of information; they act as dynamic entities that guide users through memory-related tasks, making the learning process more engaging and effective.

The effectiveness of interactive environments stems from their ability to involve multiple sensory modalities—visual, auditory, and sometimes tactile—helping to solidify memories. Research has consistently shown that multi-sensory engagement enhances memory encoding and retrieval, making interactive AR environments particularly suited for tasks requiring complex memorization or learning (Fassbender & Heiden, 2006).

3.5.3. Cognitive Load Management

While personalization and interactivity are crucial, managing cognitive load is an equally important theme in AI and AR applications for memory augmentation. Cognitive load refers to the mental effort required to process information, and it can be a limiting factor in how effective memory aid functions. AI plays a critical role here by dynamically adjusting the amount and type of information presented to users. Systems that overwhelm users with too much information can inadvertently hinder memory retention. Therefore, a balance must be struck between providing sufficient cues and avoiding information overload (Schweer & Hinze, 2007).

In studies of AR applications for spatial memory, for example, visual cues' careful timing and presentation helped users focus on relevant details without becoming cognitively overloaded (Grechkin et al., 2020). This demonstrates how AI can adjust the intensity and frequency of memory prompts to align with the user's capacity to process information, ensuring that the system augments rather than overwhelms cognitive function.

3.5.4. Ethical and Practical Implications

The application of AI and AR in memory augmentation brings significant ethical considerations, particularly concerning privacy, data security, and user dependency. AI-driven systems for personalized memory enhancement require access to extensive personal data—including user behaviour, preferences, interactions, and biometric information—to function effectively (Fischer, 2023; Makhataeva et al., 2023). For instance, Memoro's continuous audio recording raises questions about privacy and data security due to its reliance on constant data collection

(Zulfikar, Chan, & Maes, 2024). This increases the risk of misuse or unauthorized access to sensitive information, underscoring the necessity for robust privacy protocols and transparency in data handling practices. While regulations like the GDPR provide legal guidelines, their applicability to AI-driven cognitive enhancement technologies remains uncertain (Fischer, 2023). Additionally, over-reliance on AI memory aids may diminish users' ability to perform memory tasks independently, raising concerns about cognitive autonomy and the potential long-term impact on natural memory skills (Schweer & Hinze, 2007; Fischer, 2023).

Therefore, while AI and AR applications in memory augmentation present exciting opportunities, they also highlight the need for ethical frameworks that address user privacy, autonomy, and cognitive health. Ensuring these technologies support rather than replace human cognitive abilities is critical for successful implementation. Ethical design must prioritize informed consent and human-centred AI, empowering individuals rather than reducing their agency (Schweer & Hinze, 2007). Developers should promote cognitive resilience over dependency, ensuring that AI-based memory tools are designed to support rather than supplant natural memory processes (Zulfikar et al., 2024; Schweer & Hinze, 2007). Additionally, considering access and affordability is essential to prevent exacerbating inequalities, ensuring these technologies are widely accessible to avoid deepening disparities in cognitive health and educational achievement (Makhataeva et al., 2023).

3.6. Methodological Approaches in Memory Enhancement Studies

Research on memory enhancement through AI and AR employs various methods to study their effects on cognitive functions. Controlled experiments precisely manipulate variables, allowing researchers to observe participant interactions and assess immediate impacts. Meanwhile, longitudinal studies conducted in real-life settings provide insights into these memory tools' long-term effectiveness and practical applications, evaluating user engagement, adaptability, and sustained benefits. Each approach contributes unique perspectives, fostering a deeper understanding of how AI and AR can enhance memory and guide future advancements in cognitive enhancement.

3.6.1. Experimental Studies and Controlled Environments

Many early studies on memory enhancement using AI and AR focus on controlled laboratory experiments, where participants are exposed to specific tasks designed to measure short-term and long-term memory retention. For instance, research by Fassbender and Heiden (2006) on Virtual Memory Palaces (VMPs) involved creating 3D environments where participants navigated virtual spaces to memorize and retrieve information. This experimental design allowed for precise control over variables such as the type of memory tasks, the degree of immersion, and the length of exposure, making it possible to isolate the effects of the virtual environments on memory performance. These studies generally compare traditional memory methods, such as mental recall, with those enhanced by technology, offering clear evidence of the benefits of immersion for cognitive tasks.

Such experimental setups are highly valuable for exploring fundamental mechanisms of memory enhancement but may have limitations when generalizing real-world applications. The findings often rely on small sample sizes and short-term effects, which can limit their applicability to broader populations or long-term use scenarios (Fassbender & Heiden, 2006).

3.6.2. Longitudinal and Field Studies

In contrast, longitudinal studies and field experiments offer a broader view by examining how AI and AR systems impact memory over extended periods in real-life environments. For example, the study of AR applications like ExoMem, which integrates AI-generated cues into users' everyday experiences, follows participants over weeks or months to measure sustained memory improvements (Makhataeva et al., 2023). These studies are designed to assess the practical effectiveness of AI-AR tools by observing how they are used in various real-world settings, such as workplaces, educational institutions, or personal environments.

Longitudinal approaches help identify the short-term benefits of these technologies and their potential to support long-term memory retention. They also allow researchers to account for variables such as user adaptation over time and the development of dependency on memory aids. While these studies offer deeper insights into the lasting impact of memory augmentation tools, they are resource-intensive. They can be difficult to standardize, often requiring advanced analytics to process large amounts of user data (Gibbs, 2024).

3.6.3. Comparative Analysis and Control Groups

Methodological rigour in memory enhancement studies frequently involves using control groups for comparative purposes. For instance, experiments comparing memory recall in AR and VR environments versus traditional methods like the Method of Loci often involve one group using technological aids and another relying solely on traditional techniques (Huttner et al., 2018). This comparative analysis is essential for isolating the specific contribution of AI and AR technologies to memory improvements. Studies employing such methods have shown that while AR and VR enhance memory retention, AR's integration with physical spaces offers particular advantages for spatial memory tasks (Grechkin et al., 2020).

3.6.4. Cognitive Load and Usability Testing

Another key methodological focus is on cognitive load and usability testing. Studies often assess how AI-AR systems balance memory enhancement with the potential risk of overwhelming users with excessive stimuli. Researchers measure cognitive load using standardized tools such as the NASA-TLX (Task Load Index) to evaluate the mental effort required to use these memory aids effectively (Schweer & Hinze, 2007). These assessments help to fine-tune the design of AI-AR applications, ensuring that they augment cognitive processes without introducing unnecessary complexity.

3.6.5. Multimodal Approaches and Qualitative Insights

Beyond quantitative metrics, some studies incorporate multimodal approaches, blending both qualitative and quantitative methods. For example, surveys and interviews may be used alongside cognitive tests to gather subjective feedback on user experiences with AI-AR memory systems. This mixed-methods approach provides richer insights into how users perceive and interact with memory augmentation tools, capturing how these technologies impact memory beyond what can be measured through performance metrics alone (Makhataeva et al., 2023).

The variety of methodological approaches in memory enhancement studies underscores the complexity of understanding how AI and AR technologies influence cognitive processes. Each experimental, longitudinal, or comparative method contributes to a broader understanding of how these tools can be optimized to support human memory in both short-term and long-term contexts.

3.7. Critical Analysis of Current Research and Identified Gaps

The body of research exploring the integration of Artificial Intelligence (AI) and Augmented Reality (AR) for memory enhancement has produced promising findings. Current research demonstrates the potential of these technologies to improve memory retention and recall through personalized, context-aware aids and immersive environments. However, scalability and long-term efficacy issues remain underexplored, indicating significant gaps in the literature.

One notable strength of current research is the focus on personalization and contextual memory cues. AI's ability to analyze user behaviour and tailor memory aids has significantly improved cognitive support systems. For instance, systems like ExoMem have successfully demonstrated how AI can optimize memory recall by providing tailored, real-time prompts that reflect the user's environment and actions (Makhataeva et al., 2023). This approach aligns with cognitive theories such as the dual coding theory, which assumes that combining verbal and visual information enhances memory retention (Fassbender & Heiden, 2006).

Additionally, using AR to create immersive and interactive environments has been validated as an effective method for enhancing memory performance, especially for tasks involving spatial or object-based memory. Grechkin et al. (2020) showed that overlaying digital information onto real-world settings helps users establish more robust connections between the memory aid and its application context, facilitating easier recall. This method benefits users who struggle with traditional mnemonic techniques like the Method of Loci, which requires significant mental effort to visualize.

3.7.1. Identified Gaps

Despite these advances, several areas within the current research remain underdeveloped. A critical gap is the lack of longitudinal studies assessing the sustained impact of AI and AR on memory over extended periods. Most existing research is conducted in controlled environments and focuses on short-term memory improvement (Fassbender & Heiden, 2006; Huttner et al., 2018). This leaves questions about whether these technologies offer durable benefits in real-world scenarios and how continuous use might influence cognitive functions over time.

Another significant gap lies in the scalability and generalizability of these technologies. Research to date often involves small, homogeneous participant groups, such as university students or tech-savvy individuals (Fischer, 2023). The applicability of these findings to diverse populations—including older adults, individuals with cognitive impairment, or those from different cultural backgrounds—remains uncertain. Broader studies are needed to assess how AI and AR memory aids perform across various demographics to determine their viability for widespread use.

Moreover, concerns about over-reliance on these technologies warrant further exploration. While AI can enhance memory by providing context-aware prompts, there is a risk that users may become dependent on these tools, potentially diminishing their natural memory capabilities (Fischer, 2023). A balanced approach ensures that AI supports cognitive functions without undermining users' cognitive autonomy.

Here is also a lack of speculative, design-led explorations that investigate how AI and AR might transform everyday spaces for memory enhancement. Current work rarely examines how immersive, world-scale experiences such as the Method of Loci could be reimagined through design-led speculation, limiting our understanding of AI and AR's broader cognitive implications.

In summary, while integrating AI and AR in memory enhancement shows considerable promise, significant gaps remain in the current research. Addressing issues such as long-term efficacy, scalability, and generalizability is essential for the responsible development and implementation of these technologies. Future research should include design-led, speculative approaches to ensure that AI and AR memory aids are both innovative and accessible across diverse real-world contexts.

3.8. Recommended Directions in Future Research

There are a few directions that came to light, such as large-scale studies, diverse populations and scalability studies, exploring hybrid systems, and a speculative approach to envisioning future scenarios.

First, large-scale, longitudinal studies should evaluate both immediate and long-term effects of AI and AR on memory, providing insights into how sustained usage may influence cognitive functions over time (Fassbender & Heiden, 2006; Huttner et al., 2018). By examining extended periods of interaction, researchers can clarify whether memory improvements persist and how reliance on AI or AR affects natural recall processes.

Second, research involving diverse populations and scalability is vital for determining broader applicability. Studies spanning different age groups, cultures, and cognitive abilities can pinpoint variations in effectiveness, usability, and overall acceptance across user demographics (Fischer, 2023). This broader perspective is key to crafting universally accessible and beneficial memory enhancement tools.

Third, hybrid systems that fuse classical mnemonic strategies, such as the Method of Loci with AI-driven personalization, offer promising opportunities. Pairing structured techniques with adaptive, context-aware content may enrich engagement and reduce over-reliance on automated support (Makhataeva et al., 2023). Such integrated approaches can refine both the quality and sustainability of memory improvements.

Lastly, adopting a speculative, design-led approach to envision future scenarios can illuminate how AI and AR might reshape everyday environments for memory enhancement. This encourages creative exploration of immersive, world-scale experiences beyond traditional laboratory settings, revealing novel opportunities and challenges that conventional studies may overlook.

3.9.Conclusion

A range of avenues remain open for exploration, such as large-scale studies, research across diverse populations, and hybrid mnemonic systems. However, enhancing proven strategies like the Method of Loci through AI-driven personalization offers a particularly compelling path to bolster engagement and amplify the benefits of structured mnemonic techniques. AI serves here not to replace human memory but to augment and refine it. In parallel, speculative design methods, including Research through Design (RtD), offer opportunities to envision how everyday environments might be transformed through AI and AR prototypes, expanding our sense of what is possible beyond immediate practicalities.

Moving forward, this work will adopt a design-led, speculative approach to investigate the integration of AI and AR with spatial memory strategies such as the Method of Loci. By creating conceptual prototypes and artifacts that illustrate immersive, large-scale experiences turning ordinary surroundings into dynamic memory palaces, this research aims to uncover fresh insights into AI-based memory augmentation. Through iterative RtD within a speculative futures framework, it will contribute to the broader dialogue on the future of memory support, revealing novel creative possibilities and pushing the boundaries of how we conceive and utilize memory enhancement tools.

4. Related Work

The following four case studies explore memory augmentation with advanced computational technologies. Each project, Memoro, Exomem, NeverMind, and Encode Store Retrieve, addresses the challenge of supporting human memory. Their common focus on creating systems that assist in encoding, storing, and retrieving memory emphasizes the thematic cohesion of this selection.

These studies have provided valuable insights for this thesis by highlighting different design and technical considerations. Each contributes unique perspectives on how technology can complement memory, revealing both innovative strengths and limitations. Reflecting on these projects has deepened the understanding of the interplay between digital tools and cognitive processes while also emphasizing areas that require further refinement.

4.1. Case Study: Memoro

Memoro - Using Large Language Models to Realize a Concise Interface for Real-Time Memory Augmentation

In the Memoro study, the authors Wazeer Zulfikar, Samantha Chan, and Pattie Maes propose a wearable audio-based memory assistant that seamlessly integrates large language models (LLMs) to support real-time memory augmentation. The study addresses the challenge of delivering timely and relevant memory cues with minimal disruption to users during ongoing tasks. By continuously recording and encoding audio transcriptions, Memoro employs semantic search techniques that offer both explicit (Query Mode) and implicit (Queryless Mode) interactions. (Zulfikar et al., 2024)

A user study involving twenty participants demonstrated that Memoro could enhance recall confidence and reduce cognitive load, all while maintaining the flow of conversation. The system's capacity to provide concise, context-aware responses was a notable advancement compared to baseline systems lacking such nuanced retrieval.

For this thesis, Memoro offered significant takeaways on the potential of LLM-based systems to provide seamless, minimally intrusive memory cues. The work of Zulfikar, Chan, and Maes helped clarify how cognitive support can be reimagined through continuous, context-sensitive interfaces; their approach has influenced the thesis work by providing a clear example of how digital augmentation can reduce cognitive load and improve user satisfaction while also highlighting areas where future enhancements are needed. (Zulfikar et al., 2024)

4.2. Case Study: Exomem

Augmented Reality-Based Human Memory Enhancement Using Artificial Intelligence

Exomem, developed by Zhanat Makhataeva, Tolegen Akhmetov, and Huseyin Atakan Varol, addresses the challenge of supporting human memory in indoor environments through an innovative augmented reality approach. This project was designed to assist users by replacing or supplementing internal spatial representations with an external, artificial intelligence driven augmented reality overlay. The study acknowledges the cognitive strain associated with traditional memorization tasks and leverages augmented reality to present spatial maps that reflect object locations in a virtual three-dimensional format. (Makhataeva et al., 2023)

The system employs an augmented reality headset coupled with artificial intelligence powered computer vision, using a YOLO based detector and fiducial marker localization to construct an accurate spatial representation of the environment. In a pilot study involving twenty six participants, the Exomem system notably reduced mental workload, improved task completion times by approximately 27%, and significantly decreased errors in identifying object locations. These outcomes underscore the potential of integrating augmented reality and artificial intelligence to enhance spatial memory through real time, context specific interventions. (Makhataeva et al., 2023)

Despite the promising results, the study's approach encountered challenges, as the AR headset's ability to sense the environment was negatively affected by excessive natural light. For the thesis, ExoMem provided a concrete example of how augmented reality can be harnessed to transform conventional memory aids into dynamic, spatially aware tools. It highlighted the importance of minimizing cognitive load and optimizing usability, while also illustrating the need for further exploration into sustained memory enhancement over time. (Makhataeva et al., 2023)

4.3. Case Study: NeverMind

NeverMind: An Interface for Human Memory Augmentation

Oscar Rosello's NeverMind project addresses the limitations of traditional memorization techniques, which are largely based on repetition and semantic encoding and are often inefficient for long-term retention. NeverMind introduces an augmented reality interface that leverages the principles of the memory palace, aiming to transform memorization by utilizing spatial navigation and episodic memory. The goal is to enable one-shot memorization and to explore how coupling real-world architectural cues with memory palace strategies can enhance recall. (Rosello, 2017)

The project involved the creation of an augmented reality application that combines memory palace techniques with physical movement in familiar spaces. Using an augmented reality headset, participants saw mnemonic images overlaid on their environment while walking a route. Controlled experiments compared recall accuracy to paper-based memorization methods. (Rosello, 2017)

Experimental results demonstrated that users employing NeverMind achieved nearly perfect recall, with an average accuracy around 96%, compared to a steep drop-off to 35% for the paper-based method over a week. Users reported that the augmented reality method was more engaging, effortless, and enjoyable. Additionally, the research validated the hypothesis that embedding mnemonic cues within spatial contexts triggers episodic memory formation, thus enabling one-shot memory encoding. The work also serves as an open-source platform for further memory augmentation research. (Rosello, 2017)

While the augmented reality enhanced approach in NeverMind significantly improved recall, the research was limited by the small sample size of 14 participants. NeverMind contributed important insights into how traditional mnemonic strategies can be reimagined through augmented reality. Its successes and limitations have both informed the design and conceptual framing of the present research, underscoring the potential for future enhancements that further integrate spatial memory techniques with advanced digital interfaces

4.4. Case Study: Encode-Store-Retrieve

Encode-Store-Retrieve: Augmenting Memory via Language-Encoded Egocentric Perception

The Encode Store Retrieve study, authored by Junxiao Shen, John J. Dudley, and Per Ola Kristensson, presents an innovative approach to memory augmentation that centers on the efficient encoding and retrieval of lifelogged egocentric data. In addressing the challenge posed by the vast amounts of visual data generated by wearable cameras, the research introduces a system that converts individual video frames into detailed textual descriptions using a fine tuned vision language model. This transformation from visual to language encoding enables the efficient storage and search of memory fragments within a vector database. (Shen et al., 2024)

A key aspect of this work is the segmentation and embedding of language encoded data, which supports rapid retrieval when users pose memory related queries. The system utilizes advanced techniques such as OpenAI's text embedding model and a large language model (e.g., GPT 4) to generate contextually relevant responses. Evaluated on the QA Ego4D dataset, the method achieved a BLEU 4 score of 8.3, indicating a marked improvement over conventional approaches. User studies involving the HoloLens 2 further demonstrated that the system could reliably support memory retrieval, with many users rating its performance as superior to human recall in certain static scene details. (Shen et al., 2024)

While the approach successfully reduces storage needs and enhances retrieval accuracy, it stops short of addressing the integration of dynamic, long term contextual memory formation. For this thesis, the Encode Store Retrieve project provided a detailed exploration of how language can serve as an effective intermediary for transforming raw sensory data into meaningful memory cues. The insights gained from this study have been instrumental in shaping a broader understanding of how digital lifelogging and advanced language processing can converge to support human memory augmentation, even as they reveal challenges that warrant further investigation. (Shen et al., 2024)

5. Methodology

This research utilizes Speculative Design combined with Research Through Design (RtD) methodologies to explore how Artificial Intelligence (AI) and Augmented Reality (AR) technologies might support and enhance human memory through immersive experiences. These methodologies provide a robust framework for critically assessing current technological practices and envisioning near futures, moving beyond immediate practical constraints to address broader implications and possibilities. By employing a reflective and iterative approach, the research investigates practical implications through the creation and refinement of speculative artifacts, which embody both theoretical inquiries and experimental insights. This work uses Gen AI-based tools to generate images to support the narrative nature of the speculative methodology.

Below you can see the methodology diagram illustrating the relationship between speculative "What if" questions, scenario development, iterative prototyping, and reflective practices adopted in this research.

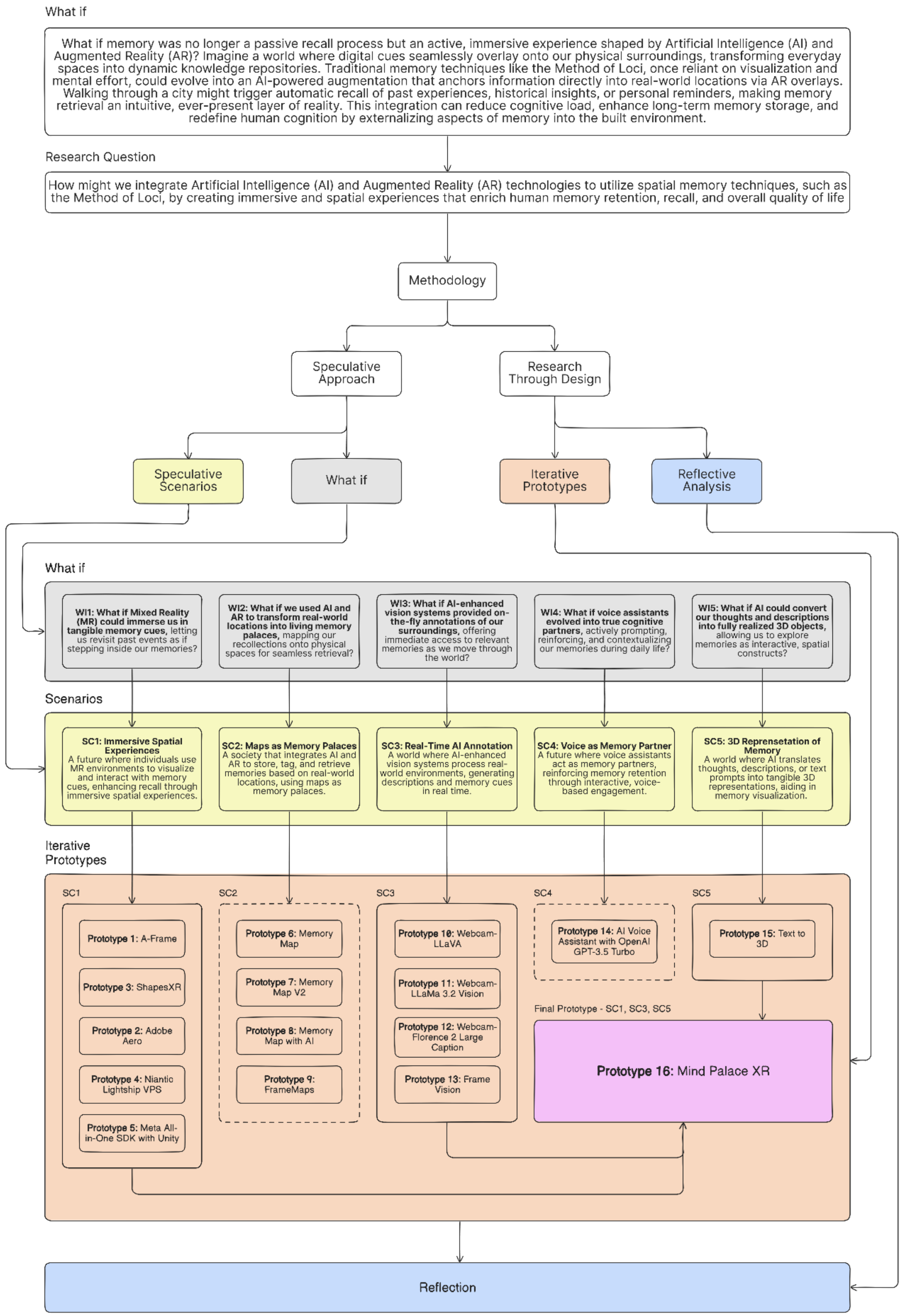

Figure 6: Methodology diagram

5.1. Speculative Design Methodology

Speculative Design, informed by the works of Dunne and Raby (2013) and Kiialainen (2022), involves imagining and critically examining potential futures through designed artifacts and scenarios. Rather than seeking immediate practical solutions, this methodology prioritizes generating debate about the potential social, ethical, and cultural consequences of future technologies. Speculative design offers alternative perspectives that encourage stakeholders to critically reflect on present circumstances and possible future outcomes. By intentionally challenging existing assumptions and norms, speculative scenarios highlight potential risks, benefits, and social transformations, providing an imaginative yet structured way of discussing emerging technological applications beyond conventional problem-solving paradigms.

5.1.1. What If's

The initial phase of this research focused on formulating five distinct "What if" questions intended to open up imaginative discussions around future possibilities of AI and AR for memory enhancement. These speculative questions deliberately envisioned concepts of human memory and technological roles, prompting creative thinking around novel forms of memory augmentation. Each question targeted different and overlapping dimensions of human-technology interaction, such as context-sensitive memory cues, personalized AR memory spaces, or adaptive memory assistance. The generated questions provided an innovative framework for further development of scenarios, ensuring diverse exploration of plausible yet ambitious futures that remained relevant within a realistic timeframe.

5.1.2. Scenarios

From these initial "What if" questions, the study developed five scenarios exploring how AI and AR might interact with human memory. Each depicted relatable moments, such as AR-enhanced city navigation with memory-triggering annotations or subtle, personalized cues during everyday tasks, showing how mundane environments could become enriched memory spaces. These narratives then guided prototype design by illustrating user interactions and potential benefits in real-world contexts.

5.2. Research through Design Methodology (RtD)

Research Through Design (RtD) emphasizes creating prototypes as an essential method of generating knowledge, directly informing theoretical understanding through design practice (Gaver, 2012). Engaging in the design process itself becomes an ongoing inquiry that challenges established paradigms and reveals unforeseen insights through continuous experimentation. The production and refinement of concrete artifacts derived from speculative scenarios serve to ground imaginative concepts in tangible experiences. Each prototype iteration is treated as a distinct research activity that systematically uncovers deeper layers of understanding, ultimately fostering a nuanced evaluation of how future memory enhancement could realistically unfold.

5.2.1. Iterative Prototyping

The iterative prototyping stage adopted a Research Through Design approach as articulated by Gaver (2012), employing prototype creation as a fundamental method of inquiry. Prototypes were developed directly from speculative scenarios, integrating AI functionalities with AR visualizations to actively explore and refine speculative concepts. Each prototype went through cycles of experimentation, evaluation, and iterative improvement. Reflection provided valuable insights regarding technical feasibility, user experience, and potential environmental considerations. This iterative process ensured continuous learning, enabling ongoing adjustments that progressively refined the research's conceptual and practical dimensions.

5.2.2. Reflective Practice and Self-Analysis

Reflective practice and self-analysis were consistently integrated into the RtD process, enabling detailed examination of technological effectiveness. Throughout the prototyping, detailed observations of scene interactions, system performance, and responses to AR and AI enhancements. This reflection examined each prototype's strengths, weaknesses, and overall effectiveness. Continuous self-analysis ensured that each iteration improved upon previous insights, effectively shaping subsequent prototypes and contributing richly to theoretical and practical understandings of memory augmentation technology.

6. Iterative Prototyping

Iterative Prototypes, within a speculative methodology and Research through Design (RtD), serve as tangible explorations of potential futures. Rather than functioning solely as problem-solving tools, these prototypes push the boundaries of what is possible, encouraging designers and audiences alike to question current norms and envision alternative scenarios (Dunne & Raby, 2013) by embodying “what if” inquiries through both scenarios and prototypes, they act as concrete outputs and reflective provocations.

In speculative design, framing “what if” statements set the stage for imagining realities just beyond the present. Such inquiries inspire scenarios that demonstrate how emerging technologies or shifting cultural practices might reshape human experiences. Whether playful, provocative, or cautionary, these scenarios outline a range of plausible futures that designers can critically evaluate (Kiialainen, 2022). From these scenarios, prototypes emerge—physical or digital representations that give form to speculative ideas and lend material presence to abstract concepts.

These Iterative Prototypes anchor the research process by enabling observation and reflection in ways that written theory alone cannot achieve (Gaver, 2012). Through interaction and immersion, they reveal insights about human behavior, societal impacts, and ethical considerations that might otherwise remain hidden. Each cycle of creation and refinement deepens the designer’s understanding, bridging the gap between imaginative speculation and pragmatic design knowledge.

6.1. What if’s, Future Scenarios and Prototypes

Posing an intriguing "what if" question initiates a process of envisioning future possibilities, spanning from the immediate to more ambitious projections (Dunne & Raby, 2013). Each hypothetical scenario invites us to consider various outcomes for society, technology, and human behavior. This work favours a perspective focused on the near future, concentrating on options that are both realistic and informative for current decision-making.

Designers, researchers, and innovators use these projected scenarios to identify potential opportunities and obstacles in developing new services, products, or systems. The approach calls for constructing alternative narratives that connect abstract ideas with practical applications, offering clear indications of what may come. These scenarios provide a foundation for reflecting on design choices and the likely influence on experiences (Dunne & Raby, 2013).

By iterating through the development and refinement of tangible prototypes, the speculative design process helps reveal how today's decisions may influence future outcomes (Dunne & Raby, 2013). Focusing on near-term prospects ensures that the study remains applicable to current challenges, encouraging thoughtful discussion and informed planning without relying solely on abstract conjecture (Kiialainen, 2022). In the following sections, What if’s are introduced, forming the basis for imagined scenarios from which prototypes are created using present-day technologies to offer a glimpse into the future.

The research through design (RTD) approach was adopted for creating these prototypes, a strategy that has influenced the overall research. The RTD methodology not only grounds abstract ideas in concrete artifacts but also fosters an iterative, reflective dialogue between design practice and research. By enabling prototypes to serve as both practical outcomes and catalysts for theoretical inquiry, the approach enriches the understanding of design’s potential to shape future possibilities. (Gaver, 2012)

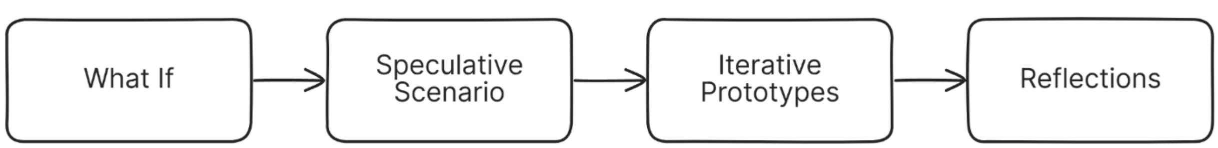

Figure 7: Iterative Prototype stages

The overall structure weaves together "What if?" questions, future scenarios, and prototypes. It starts by posing thought-provoking questions that ignite innovative thinking and lay the foundation for exploring various possibilities. Each scenario unfolds into multiple prototypes that serve as tangible interpretations of potential outcomes. Grouping these prototypes around key themes creates a systematic progression from speculative ideas to actionable insights. This approach enables designers to bridge abstract concepts with practical applications effectively.

6.1.1. Concept 1: Immersive Spatial Experiences

What if (1):

What if Mixed Reality[1] (MR) could immerse us in tangible memory cues, letting us revisit past events as if stepping inside our memories?

Future Scenario (1):

Aisha slips on her lightweight MR headset, immediately seeing a glowing café symbol that sparks recognition. Instead of scrolling through messages, she follows luminous orbs shaped like coffee beans floating along the sidewalk, guiding her effortlessly. Approaching the entrance, a translucent 3D model of two coffee cups appears, vividly recalling their last visit. Nearby, a floating photo of her friend's smiling face triggers a replay of their laughter, mingling with the sensory cue of fresh espresso aroma. Passersby glance curiously at her joyful expression, unaware she's immersed in these rich visual memory cues. Stepping inside, a final image from their past meeting gently fades, anchoring her back into reality. In this new age, memories are vividly woven into daily life through symbolic visuals and immersive cues.

Figure 8: An image depicting immersive spatial experiences

[1] Mixed Reality (MR): Interactive blend of real and virtual content

6.1.1.1.Prototype 1: A-Frame

Prototype 1 offers an innovative blend of 360° imagery[2] and interactive 3D models to create an immersive spatial experience. Inspired by the method of loci[3], it embeds digital artifacts in panoramic backdrops to enhance memory.

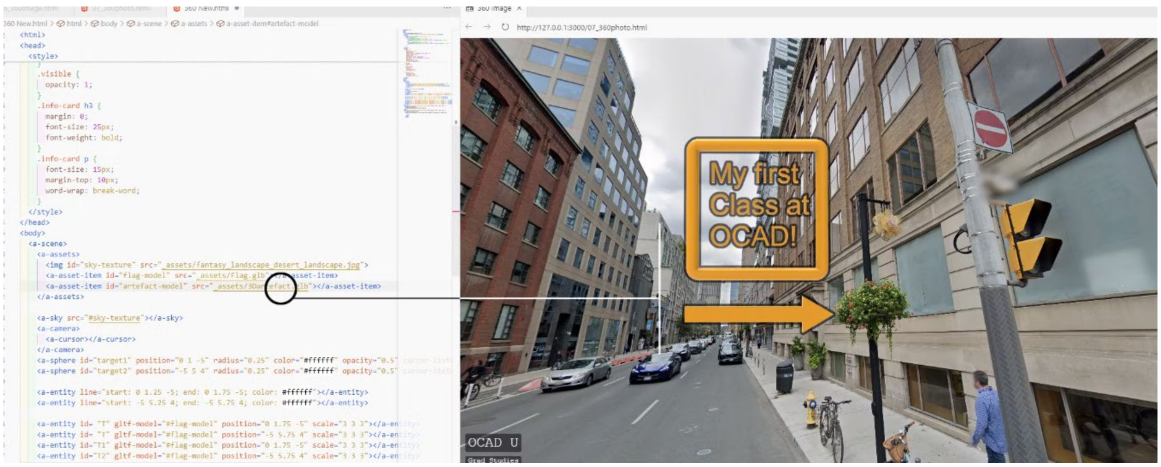

Figure 9: Prototype 1 – A-Frame

Intent, Impact and Key Takeaway

The study aimed to explore whether positioning objects within a 360° environment fosters spatial associations that aid recall. It was observed that while panoramic backdrops effectively anchored digital artifacts, the purely virtual setting limited the formation of real-world connections, suggesting that incorporating physical location cues might be necessary. Ultimately, the key takeaway is that although immersive environments can be beneficial, blending them with actual surroundings is likely to enhance their mnemonic impact.

The Idea

The initial concept for this prototype was to create an immersive environment using 360° imagery, integrating 3D models within a virtual scene. Inspired by traditional spatial memory

[2] 360° imagery: Panoramic images offering a full surround view
[3] Method of loci: Mnemonic strategy using spatial memory for recall

technique (method of loci), the idea focused on embedding digital objects contextually within a panoramic backdrop to help users form stronger mental associations.

Development

A-Frame[4], a web framework for building virtual and augmented reality experiences with HTML[5] and JavaScript, served as the primary tool. The development process involved setting up a skybox and loading a 360° image sourced from Google Street View. Integrated a GLTF 3D model into the scene, adjusting its position and scale to explore how easily users could interact with and remember spatially placed information.

Figure 10: Prototype 1 development stages

Tech Stack

A-Frame (WebVR framework), JavaScript, HTML, GLTF models (3D)

Reflection

Reflecting on this prototype revealed its strengths in rapid iteration and accessibility. The web-based nature of A-Frame allowed for quick adjustments and tests. However, while the initial integration of 3D artifacts within a 360° environment was promising, the lack of direct AR overlay[6] limited the level of real-world contextualization. This experience, however, laid the groundwork for understanding how spatial cues might be represented in immersive settings.

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[4] A-Frame (WebVR framework): HTML-based tool for building VR in the browser. Available at: https://aframe.io/
[5] HTML / CSS / JavaScript: Core web technologies for page structure and styling
[6] AR overlay / Augmented Reality (AR): Digital visuals superimposed on the physical world

What Worked

The setup was straightforward, featuring a relatively simple coding structure that enabled quick prototyping and testing. Additionally, the concept of placing virtual objects in a panoramic setting provided a foundational understanding of spatial context.

What Did Not Work

The approach encountered several challenges. Firstly, the environment had limited real-world anchor points, as it was purely virtual rather than being integrated as an AR overlay. Secondly, there was a noticeable absence of interactive features, which prevented users from engaging meaningfully with the embedded 3D objects. Finally, the system did not incorporate AI-driven context awareness at this stage.

This prototype showcased immersive 360° experiences with digital artifacts enhancing spatial recall. The key takeaway is that merging virtual cues with real-world anchors can boost memory. This experiment lays the foundation for more integrated, context-aware designs.

6.1.1.2. Prototype 2: Adobe Aero

Prototype 2 offers an innovative approach to integrating augmented reality with the physical world. It utilizes Adobe Aero[7] to anchor 3D artifacts in real-world locations, enhancing the tangibility of memory cues. The experiment sets a new benchmark in AR experiences by blending digital content with familiar environments.

Figure 11: Prototype 2 – Adobe Aero

Intent, Impact and Key Takeaway

The experiment was designed to test location-based AR anchoring as a means to create more tangible memory cues. It demonstrated that real-world overlays are generally more memorable than purely virtual scenes; however, the lack of AI-driven personalization appeared to reduce some of the potential recall benefits. Ultimately, the key takeaway is that while immersion itself is beneficial, blending it with actual environments likely enhances the mnemonic impact.

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[7] Adobe Aero: AR platform for anchoring 3D content into real-world settings. Available at: https://helpx.adobe.com/aero/get-started.html

The Idea

This prototype aimed to bring the concept closer to a genuine AR experience. By placing 3D artifacts in the real world, the objective was to explore how location-based anchors might enhance recall and situate information more tangibly in a user's actual environment.

Development

Using Rhino[8] to model a 3D artifact and Adobe Dimension[9] for texturing, the final model was imported into Adobe Aero. Aero enabled location-based AR placement, allowing the artifact to be anchored at a specific outdoor location, such as near the 205 Richmond building at the OCAD U campus. Access was provided via a link or QR code[10] that, when scanned with a mobile device, overlaid the 3D object in the user's live camera feed.

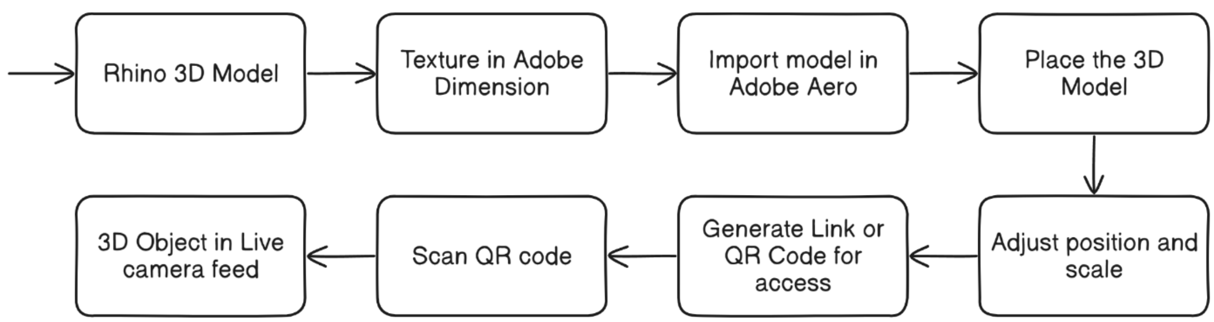

Figure 12: Prototype 2 development stages

Tech Stack

Adobe Aero (AR platform), Rhino (3D modelling), Adobe Dimension (texturing)

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[8] Rhino (3D modelling software): Tool for creating complex CAD-based 3D shapes. Available at: https://www.rhino3d.com/
[9] Adobe Dimension: Application for designing and rendering 3D scenes. Available at: https://www.adobe.com/products/dimension
[10] QR code: Machine-readable code linking to digital data

Reflection

This approach brought the research one step closer to a practical scenario. Users could visualize spatially placed information in a familiar context, potentially strengthening memory associations. However, without integrated AI or interactive elements, the experience offered limited adaptability or personalization.

What Worked

The approach succeeded through several key aspects. Firstly, easy location-based placement made it simple to anchor digital content to real-world coordinates. Additionally, fast loading and a user-friendly mobile experience contributed to a smooth overall operation. Finally, the integration with Adobe's creative suite facilitated an efficient texturing and design workflow.

What Did Not Work

The approach encountered several challenges. It relied on QR codes or links instead of offering a continuous AR flow, which disrupted the immersive experience. Additionally, there was minimal interactive functionality and a lack of contextual AI assistance to tailor memory cues. Lastly, the limited complexity in object interaction further restricted the potential for richer memory encoding strategies.

This prototype showcased the practical benefits of location-based AR anchoring for improving memory retention. It highlighted both the immersive strengths and the limitations posed by minimal interactive functionality. Overall, the findings emphasize the potential of combining digital overlays with real settings to pave the way for future enhancements.

6.1.1.3.Prototype 3: ShapesXR

Prototype 3 offers an innovative mixed reality approach that boosts memory through spatial engagement. It blends 3D object manipulation with collaborative interaction in physical settings. This method sets the stage for future AI-enhanced MR experiences.

Figure 13: Prototype 3 - ShapesXR

Intent, Impact and Key Takeaway

The study tested whether mixed reality using Quest 3 enhances memory through realistic three dimensional object manipulation. Active spatial engagement, such as walking and touching objects, appears to strengthen memory encoding, although the lack of artificial intelligence customizations limited some features. The key takeaway is that while immersion is beneficial, blending it with actual environments and artificial intelligence may further boost memory.

The Idea

The third prototype focused on exploring Mixed Reality (MR) through the ShapesXR[11] platform and Meta Quest 3[12]. The idea was to visualize and manipulate 3D models in a more immersive environment where users could walk around and interact with information cues.

Development

Using the ShapesXR web interface, a 3D artifact was imported and viewed through Meta Quest 3. The app provided collaborative features and spatial manipulation tools. Users could experience these objects in MR, seeing digital content integrated seamlessly with their physical surroundings.

Tech Stack

ShapesXR (MR design platform), Meta Quest 3 (headset)

Reflection

This experience highlighted the promise of MR for memory augmentation. Being able to navigate and interact with spatial elements naturally suggests that MR could foster deeper cognitive engagement. Still, without integrated AI or more complex narrative elements, the prototype served primarily as a proof-of-concept for spatial immersion.

What Worked

The approach proved successful in several ways. It enabled easy placement and manipulation of three-dimensional assets in mixed reality, supported collaboration by allowing multiple users to share the same environment, and enhanced spatial presence, which may correlate with stronger memory encoding.

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[11] ShapesXR (MR design platform): Software for prototyping MR experiences. Available at: https://www.shapesxr.com/
[12] Meta Quest 3 (headset): VR/MR headset from Meta (formerly Oculus). Available at: https://www.meta.com/ca/quest/quest-3/

What Did Not Work

The approach fell short in several areas. It was limited to basic interactions without advanced features like personalization or automated contextual cues. It also relied on mixed reality hardware, which raised concerns about accessibility and equipment availability. Additionally, there was no integration with artificial intelligence for contextual understanding or memory retrieval guidance.

This prototype showcased how MR can strengthen memory via active spatial interaction. It highlighted immersive design's potential alongside its current limitations. Overall, it points to a promising future for MR in cognitive enhancement.

6.1.1.4.Prototype 4: Niantic Lightship VPS

Prototype 4 showcases the innovative use of Niantic Lightship VPS to anchor AR content with unparalleled precision, merging physical locations with digital memory. It highlights the integration of Unity and ARDK to establish a stable reference frame for persistent AR placements.

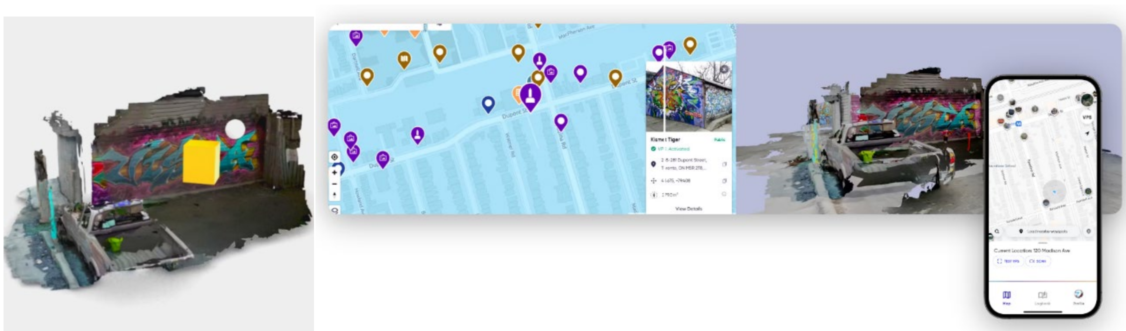

Figure 14: Prototype 4 - Niantic Lightship VPS

Intent, Impact and Key Takeaway

The intent was to enable highly precise, persistent AR placement that creates stable memory anchors. Although the improvements in accuracy enhanced the connection between a place and its associated memory, technical issues hindered the integration of AI. The key takeaway is that persistent, location-based AR is essential for reliable mnemonic anchors, and future prototypes should incorporate adaptive or contextual elements to enrich recall.

The Idea

This prototype aimed to leverage Niantic Lightship's Visual Positioning System (VPS) to achieve highly accurate, location-based AR placement of 3D artifacts. The idea was to combine precise environmental mapping with AI potential, ultimately creating more dynamic and responsive spatial memory aids.

Development

The approach involved using Unity[13] for development and Niantic's Lightship VPS for precise location anchoring. By integrating Lightship's environment scanning and mapping capabilities, the plan to achieve stable, persistent AR objects that would retain their placement over time and across multiple user sessions was challenging due to evolving Unity engine versions and ARDK updates; this development faced technical hurdles, delaying full integration.

Tech Stack

Unity (game engine), Niantic Lightship VPS (precision AR anchoring), ARDK

Reflection

The potential of Niantic Lightship VPS lies in its robust mapping and persistent content anchoring, allowing a stable reference frame for memory cues. While not fully realized yet, the platform promises an enhanced user experience with more reliable spatial references and an eventual incorporation of AI-driven responses.

What Worked

The project demonstrated clear potential for the persistent and accurate placement of AR artifacts in real-world locations. Additionally, the underlying platform is aligned with location-based interactivity, indicating that it could support future integration with AI and user-specific data.

What Did Not Work

Technical challenges emerged due to ongoing updates in Unity and ARDK, which made implementation difficult at this stage. Additionally, there was an absence of a fully functioning prototype that could be integrated with AI, and delays were encountered in achieving the desired complexity of interactive, context-aware functionality.

[13] Unity (game engine / AR development): Cross-platform engine for real-time 3D apps. Available at: https://unity.com/

This prototype showcased the potential for establishing reliable, location-based AR anchors despite technical hurdles. It sets the stage for future enhancements that incorporate adaptive, context-aware elements to enrich spatial memory recall.

6.1.1.5.Prototype 5: Meta All-in-One SDK with Unity

Prototype 5 showcases the integration of a striking, preloaded 3D artifact using the Meta All-in-One SDK[14] with Unity on the Meta Quest 3. It highlights the potential of consistent visual cues to trigger spatial memory within an augmented reality environment.

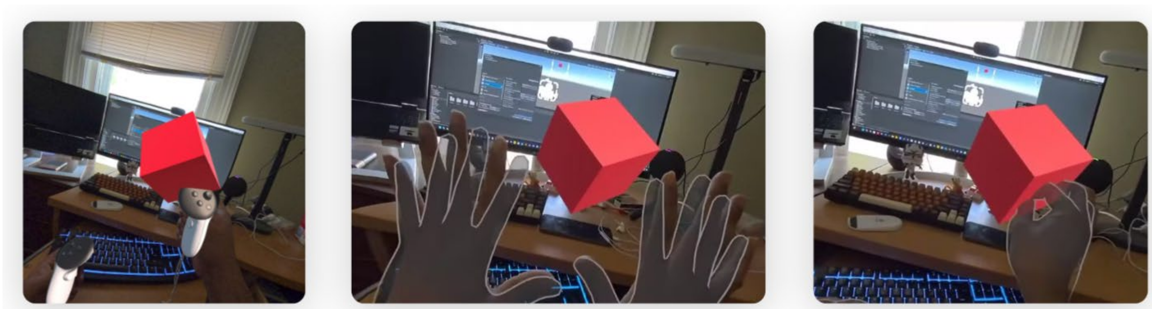

Figure 15: Prototype 5 – Meta all-in-one SDK building blocks

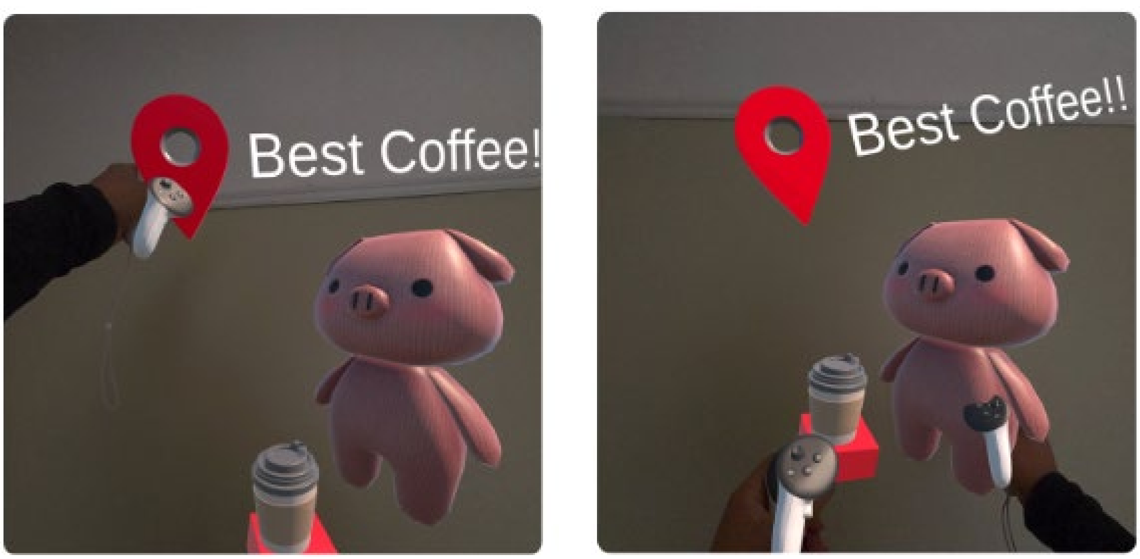

Figure 16: Prototype 5 – Meta all in one SDK sample scene

Intent, Impact and Key Takeaway

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[14] Meta All-in-One SDK: Toolkit for developing apps on Meta's VR/AR headsets. Available at: https://assetstore.unity.com/packages/tools/integration/meta-xr-all-in-one-sdk-269657

The intent was to determine whether a single, distinctive 3D cue, when encountered repeatedly, enhances recall over time. Consistent exposure helps associate a particular memory with a specific location or object; however, deeper context or additional tasks are required for robust long-term retention. In summary, while visual distinctiveness alone can spark memory, layering narrative or utilizing AI-driven relevance better aligns with complex recall needs.

The Idea

This prototype centred on deploying preloaded 3D artifacts into an Augmented Reality environment using the Meta All-in-One SDK on a Meta Quest 3 device. The primary goal was to assess how static, vividly rendered 3D memory cues represented by a playful, memorable object could influence user recall when repeatedly encountered in a spatial context.

Development

The development process involved setting up Unity with the Meta All in One SDK to facilitate augmented reality rendering on the Meta Quest 3. A three-dimensional artifact, such as a toy pig or another distinctive object, was imported and positioned within the augmented reality scene. Basic interactions were enabled, allowing users to examine the artifact closely or reposition it using the headset controllers or hands. Additionally, the visual appearance of the artifact, including its materials, colours, and scale, was carefully tailored to create a striking and memorable presence in the user's environment.

Tech Stack

Unity (game engine), Meta Quest 3 (headset), Meta All-in-One SDK

Reflection

This prototype offered a straightforward opportunity to observe how a singular, preloaded 3D artifact could function as a memory cue within an AR environment. By placing a visually distinctive object in the user’s field of view through the Meta Quest 3, the prototype aimed to determine if repeated encounters could strengthen recall over time. Although the setup was minimal—no navigation or narrative layers—the simple presence of a memorable object suggested that consistent exposure in a spatial context may aid in reinforcing certain memories.

What Worked

The Meta All in One SDK and Unity pipeline provided a reliable way to anchor the three-dimensional artifact in the real-world environment. The chosen object was visually distinct enough to stand out, potentially serving as a meaningful spatial cue. The system allowed for viewing and maneuvering around the artifact with minimal friction, enabling direct spatial engagement and enhancing its memorability.

What Did Not Work

Without additional context, interactive elements, or narrative layers, the artifact's role as a memory cue remained limited. Beyond simply observing the object, there were no tasks or prompts that encouraged deeper cognitive association, leaving its potential as a memory cue largely theoretical.

This prototype showcased how a single, vivid 3D cue can enhance recall over repeated encounters. It also underscored the need for additional narrative layers or interactive elements to achieve deeper, long-term memory retention.

6.1.1.6. Concept 1: Summary

The Concept 1 scenario explored prototypes that utilized both virtual and augmented reality to enhance memory through spatial cues. Prototype 1 used A-Frame to integrate 360° imagery with 3D models, showing that immersive virtual settings can anchor memory but might benefit from real-world context. Prototype 2 employed Adobe Aero to place digital artifacts in physical spaces, highlighting that location-based AR improves memorability despite limited interactivity. Prototype 3, using ShapesXR in Meta Quest 3, demonstrated that mixed reality with active spatial engagement can boost memory, though it lacked advanced personalization. Prototype 4 leveraged Niantic Lightship VPS with Unity to create persistent AR anchors with high precision, while Prototype 5 integrated a visually striking 3D cue using the Meta All-in-One SDK with Unity, suggesting that consistent exposure to distinctive objects can trigger recall yet may require additional narrative layers for robust long-term retention.

6.1.2. Concept 2: Maps as Memory Palaces

What if (2):

What if we used AI and AR to transform real-world locations into living memory palaces, mapping our recollections onto physical spaces for seamless retrieval?

Scenario (2):

While strolling through her bustling neighborhood, Mari uses an app that turns each street corner into part of her personalized memory palace. At the bakery, a small holographic bookshelf hovers, reminding her of the cookbook she borrowed from a neighbour. Near the florist, virtual petals swirl around her, prompting her to recall the time she bought flowers for her sister's graduation. The app ensures these cues feel natural, placed in exact spots where those memories first took shape. Neighbours start swapping their own memory markers, creating a shared map of personal highlights that sparks conversation among passersby. Families introduce their children to stories rooted in these everyday locations, embedding bits of their lives in the very pavement they traverse. Over time, a simple trip to pick up groceries transforms into a gentle journey through collective recollection.

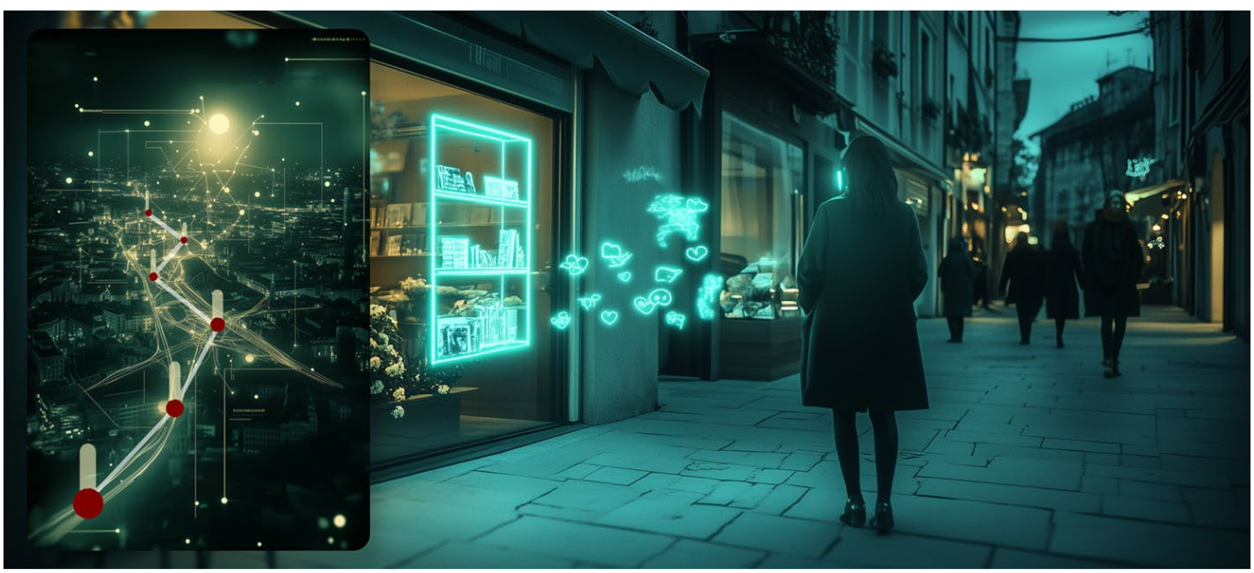

Figure 17: An image depicting maps as memory palaces

6.1.2.1.Prototype 6: Memory Map – Pin Your Moments

Prototype 6 offers an innovative approach to organizing personal memories by allowing users to manually pin photos and attach descriptive labels. It sets the stage for future enhancements with AI and AR integration, emphasizing user-driven curation.

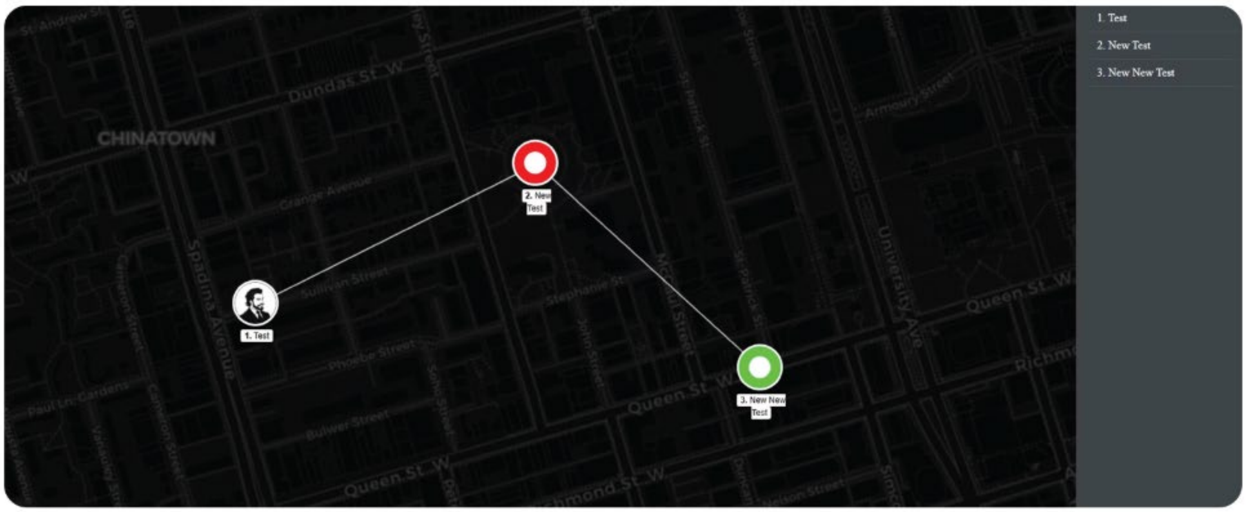

Figure 18: Prototype 6 - Memory Map, pin your moments

Intent, Impact and Key Takeaway

The intent was to manually anchor photos and labels to locations, testing user-driven spatial memory organization. This manual input reinforces a sense of ownership over memories; however, it falls short of providing automated insights and lacks integration with AI and AR. Ultimately, the key takeaway is that personal curation strengthens memory links, and incorporating AI could streamline the process while offering richer mnemonic cues along with augmented reality capabilities.

The Idea

This version focused on a more user-driven approach, allowing the manual uploading of images and labelling. While it did not incorporate LLaVA directly, the idea was to test how users would interact with a memory-mapping system when they could manually select images, assign descriptions, and position markers. It aimed to refine the interface, and user flows essential for more advanced AR and AI integrations later.

Development

The web UI was developed using HTML and JavaScript, with the Leaflet[15] mapping library at its core. It involves clicking on the map to add a photo and a textual label, allowing users to anchor memories to specific locations. Additionally, markers can be dragged and clustered for enhanced visualization, all within a simple, familiar interface designed for effective management and browsing of memories.

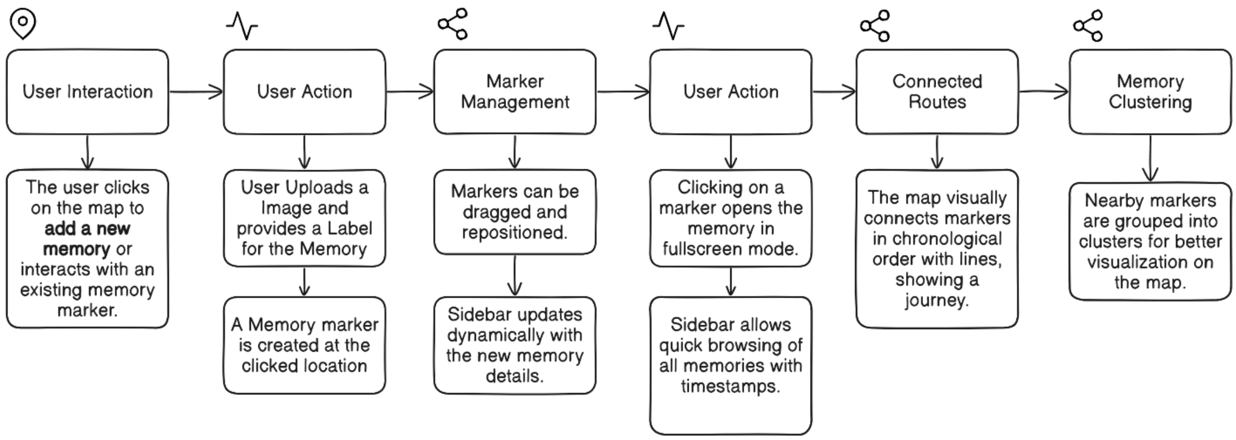

Figure 19: Prototype 6 development workflow

Tech Stack

HTML/JavaScript, Leaflet (mapping library)

Reflection

This simpler, manual variant served as a usability test. Without automatic AI description, the emphasis was on user input and interaction design. Users' direct labelling and positioning of markers offered insight into how they naturally organize and recall memories spatially.

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15 Leaflet (interactive mapping library): JavaScript library for maps and markers. Available at: https://leafletjs.com/

What Worked

The project featured a straightforward user workflow where one simply clicked, uploaded, and labelled, streamlining the overall experience. Marker clustering[16] and sidebar integration further enhanced map clarity, while intuitive interactions empowered users to shape their own memory narratives.

What Did Not Work

The system faced several challenges. The absence of automated AI insights necessitated reliance solely on user-provided text, and there was no direct augmentation or contextual adaptation to aid recall. Additionally, scalability became an issue, as managing a large number of markers proved difficult without automated filtering.

This prototype showcased the effectiveness of a simple, manual interface in reinforcing personal memory links. It underscored the potential for richer, automated mnemonic cues and spatial organization through web UI technologies.

[16] Marker clustering: Technique grouping map markers to avoid visual clutter

6.1.2.2.Prototype 7: Memory Map V2

Prototype 7 offers an innovative mapping experience by refining the UI/UX to handle complex spatial data with modern web technologies. It seamlessly integrates advanced visualization features such as marker clustering and chronological connection lines, setting the stage for future enhancements.

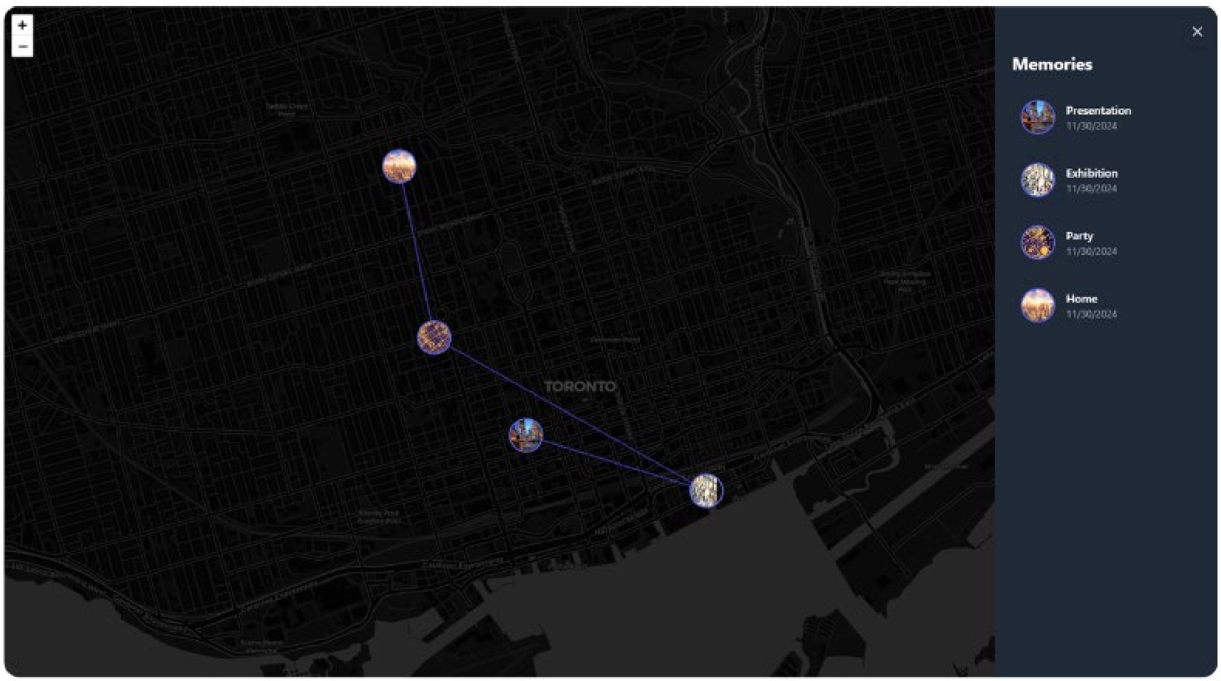

Figure 20: Prototype 7 - Memory Map V2

Intent, Impact and Key Takeaway

The intent is to refine the UI/UX to handle more complex spatial data while preparing for advanced features like clustering in web-based memory curation. This enhancement is expected to lead to better visual organization through clustering and connecting lines, which helps users track memories more coherently, even though it still relies on user input. Ultimately, the key takeaway is that a scalable, user-friendly mapping framework serves as a strong foundation for future AI/AR integration, enhancing recall through improved visualization.

The Idea

Building on the previous iteration, this V2 integrated modern web technologies, React[17], Leaflet, Tailwind CSS[18], and TypeScript[19], for a more polished, scalable, and maintainable codebase. The idea was to incorporate best practices improved UI/UX design, and set the stage for advanced features like AI integration, clustering, and route visualization.

Development

Rebuilt with a React frontend and Leaflet for mapping, this version introduces a cleaner code structure based on a component-driven architecture. It features enhanced functionalities such as marker clustering, drag-and-drop repositioning, chronological connection lines, and improved responsiveness. Additionally, the update offers dark-themed[20] aesthetics and a more streamlined user experience.

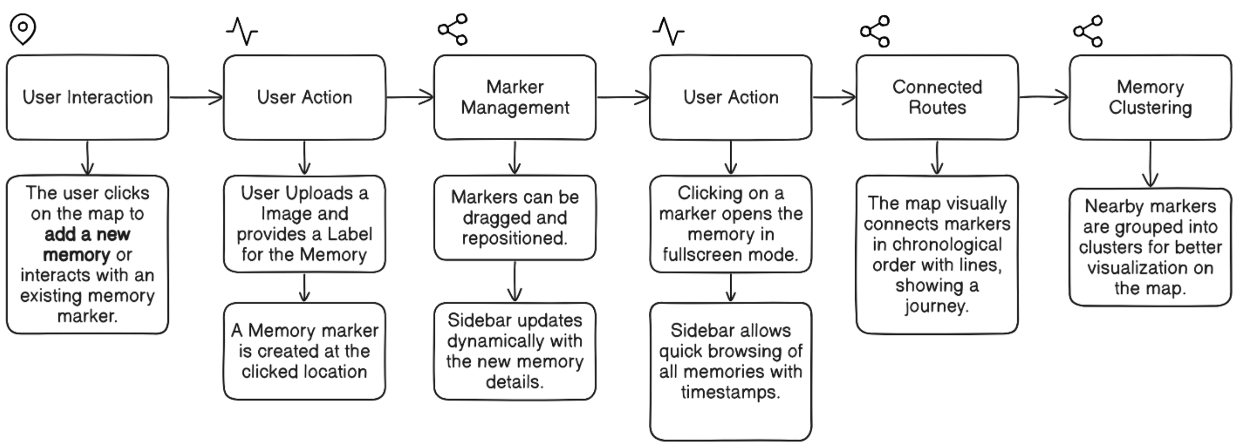

Figure 21: Prototype 7 development Workflow 1

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[17] React (front-end framework): JavaScript library for building interactive UIs. Available at: https://react.dev/
[18] Tailwind CSS: Utility-first CSS framework for rapid UI design. Available at: https://tailwindcss.com/
[19] TypeScript: Superset of JavaScript adding static typing. Available at: https://www.typescriptlang.org/
[20] Dark-themed interface / dark-themed map: UI styling that uses darker colour palettes

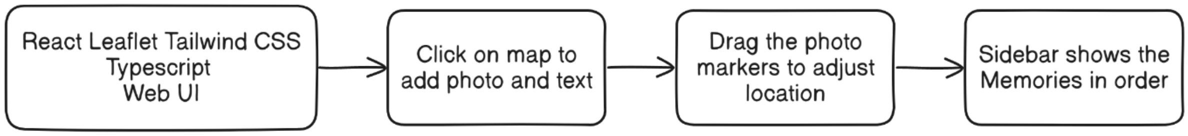

Figure 22: Prototype 7 development workflow 2

Tech Stack

React (front-end), Leaflet (map), Tailwind CSS (styling), TypeScript

Reflection

This iteration underscored the importance of robust architecture and a polished interface. While not adding new AI functionalities at this stage, it provided a stable platform. The improved code organization and user-centric design would ease future integrations of AI-driven context[21] and memory aids.

What Worked

The updates resulted in a more maintainable and scalable codebase, enhanced interface responsiveness with greater aesthetic coherence, and improved navigation and memory organization.

What Did Not Work

Although there were significant improvements, several aspects did not work as intended. The system still lacked real-time AI integration and AR overlays, and it continued to rely on manual data input for memory content. Additionally, the setup and build process remained more complex compared to simpler prototypes.

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[21] AI-driven context: Automatic retrieval of contextual information using AI

This prototype showcased significant improvements in design and code scalability, providing a robust platform for further integration of advanced memory curation features. It underscores the critical balance between immediate functionality and future-proofing in evolving digital experiences.

6.1.2.3. Prototype 8: Memory Map with AI

Prototype 8 offers an innovative blend of AI-generated captions with spatial memory mapping, transforming the way users document and interact with their memories. It integrates interactive mapping, webcam capture[22], and automated labelling to enrich the narrative experience with minimal user effort.

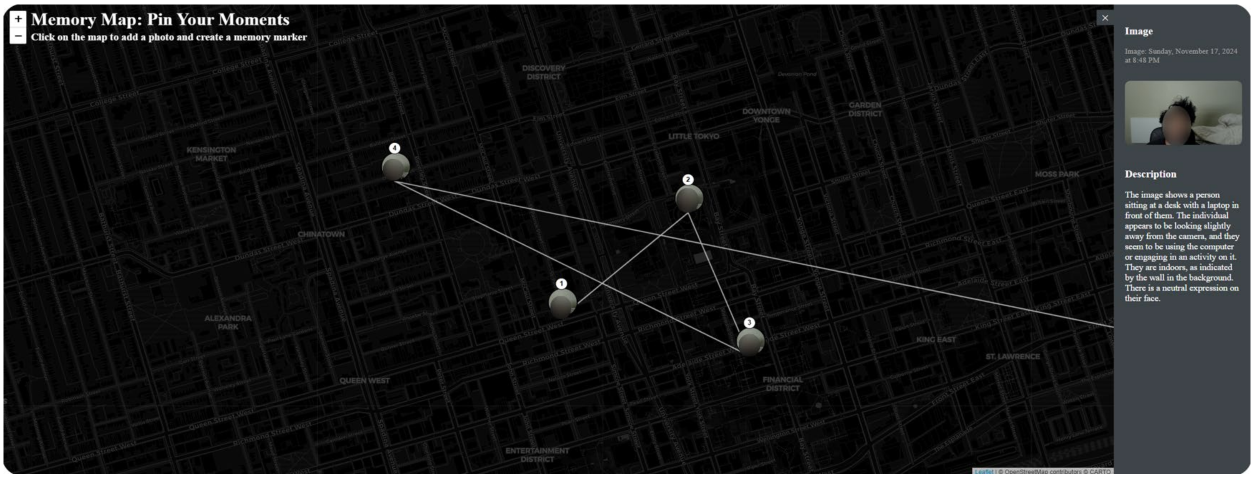

Figure 23: Prototype 8 - Memory Map with AI

Intent, Impact and Key Takeaway

The intent is to combine AI-generated captions with spatially pinned memories to reduce user effort while enriching descriptions. This automated labelling speeds up the process of tagging memories and adds valuable context, which in turn boosts engagement with the memory timeline. The key takeaway is that although AI-generated captions enhance recall by offering consistent, semantic insights, the reliance on 2D maps still limits the potential for immersive interactions.

The Idea

This prototype combined the strengths of previous approaches, including interactive mapping, webcam capture, and memory anchoring with AI-driven image descriptions. The concept was to

[22] Webcam capture: Live image feed from a connected camera

offer a more integrated solution, where each pinned memory automatically received a descriptive caption from LLaVA, enhancing the spatial narrative with semantic insights.

Development

Using a Flask[23] backend with Python[24], OpenCV[25] is used for webcam capture, while the front end is managed by Leaflet. In this version, images are captured upon map interaction and then sent to the Large Language and Vision Assistant[26] (LLaVA) for immediate descriptions. The system displays connected memory points, complete with timestamps and detailed sidebars, and incorporates enhanced UI features such as a full-screen gallery view and a dark-themed map interface.

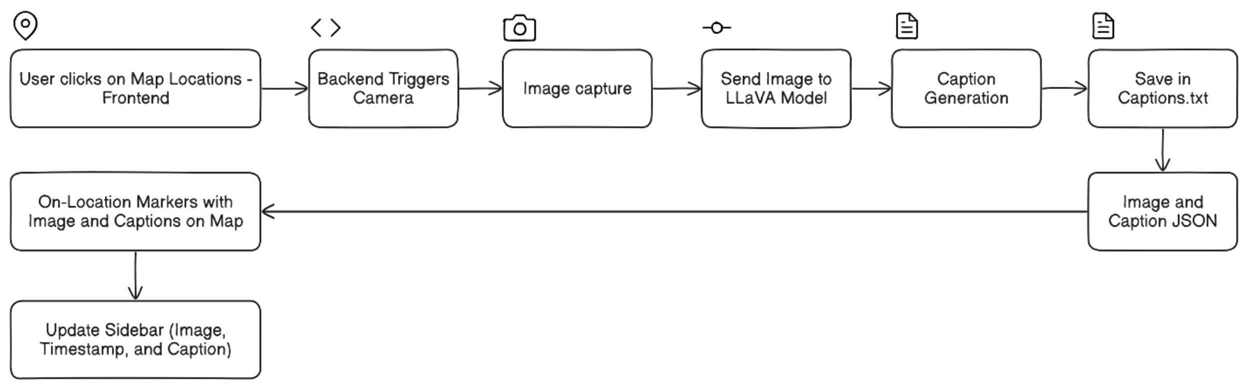

Figure 24: Prototype 8 development workflow

Tech Stack

Flask (Python web framework), Python, Leaflet (map), OpenCV (image capture), LLaVA (image-to-text)

[23] Flask (Python web framework): Lightweight Python framework for web apps
[24] Python: High-level language for versatile programming tasks. Available at: https://www.python.org/
[25] OpenCV (computer vision library): Python library for real-time image processing. Available at: https://opencv.org/
[26] Large Language and Vision Assistant (LLaVA): AI model combining text and image processing. Available at: https://github.com/haotian-liu/LLaVA

Reflection

This prototype represented a near-ideal synthesis of the project's goals—spatially anchored, AI-augmented memories. Reflecting on it, it was clear that while the user experience improved significantly, there remained opportunities for even deeper personalization, adaptive learning, and AR-based overlays in future iterations.

What Worked

The system's strengths are evident in several key areas. Automated, AI-generated captions streamlined the memory documentation process, reducing the manual effort required to record details. Additionally, the chronologically connected markers provided users with a narrative journey, enhancing the way memories were experienced over time. The introduction of a full screen gallery and sidebar further improved the ease of browsing and recalling past events, making the overall experience more intuitive and engaging.

What Did Not Work

The main issues encountered were that the lack of AR-specific integration limited the experience to a 2D map interface. There were also scalability concerns, particularly when dealing with large sets of images or continuous processing, and no on-device personalization or adaptive features had been integrated yet.

This prototype showcased the potential of combining AI captions with spatially pinned memories to enhance recall and user engagement. While it significantly streamlined memory documentation, it also highlighted opportunities for deeper personalization and immersive AR enhancements.

6.1.2.4.Prototype 9: Frame Maps

Prototype 9 offers an innovative approach to merging augmented reality with AI-powered spatial mapping. It integrates wearable-captured photos with real-time AI captions to create a dynamic, location-based memory exploration tool.

Figure 25: Prototype 9 - Frame Maps

Intent, Impact and Key Takeaway

The project aimed to visualize AI-labeled, wearable-captured photos on a live map, connecting memory events with specific places in near real-time. This approach enabled map-based exploration that made it easier to recall locations and moments, although the use of IP-based geolocation sometimes limited precise spatial anchoring. Ultimately, the key takeaway is that real-time AI captioning combined with mapping effectively merges memory creation with location, suggesting a deeper synergy between AR and AI for achieving more precise anchoring.

The Idea

Frame Map combines the power of Brilliant Labs Frame smart glasses[27], the LLaVA Vision-Language model[28], and OpenStreetMap[29] to create an interactive tool for capturing and visualizing spatially contextualized photos. The system captures images, generates AI-driven descriptions, and maps them to geolocations, enabling users to visualize their captured moments on an interactive map.

Development

The project used Python to enable communication between the Brilliant Labs Frame, LLaVA model, and OpenStreetMap frontend. Captured images were processed using the locally hosted Large Language and Vision Assistant (LLaVA) model via Ollama[30] to generate textual captions, while geolocation data was retrieved using IP-based services. The metadata, including photo paths, captions, and geolocations, was stored in a JSON file for visualization on a Leaflet-based map interface.

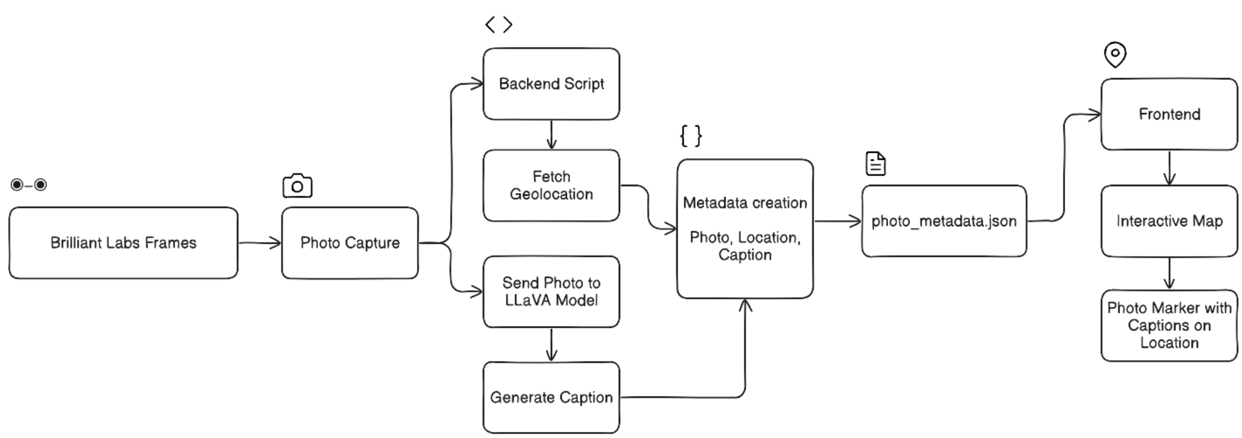

Figure 26: Prototype 9 development workflow

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[27] Brilliant Labs Frame (smart glasses): Wearable device for hands-free photo capture. Available at: https://brilliant.xyz/products/frame
[28] Vision-Language model: AI that interprets and generates text based on images
[29] OpenStreetMap: Crowdsourced global map data platform. More information at: https://www.openstreetmap.org/about/api/
[30] Ollama (local model hosting API): Tool for hosting AI models locally via API. Available at: https://ollama.com/

Tech Stack:

Brilliant Labs Frame (smart glasses), Python, LLaVA, Leaflet (map), Ollama (model hosting), IP-based geolocation

Reflection

The project successfully demonstrated the integration of AI-driven visual descriptions with spatial data visualization. The interactive map provided a user-friendly interface for exploring captured moments. However, the reliance on IP-based geolocation limited the accuracy of spatial metadata, highlighting the need for GPS-based enhancements[31] in future iterations.

What Worked

The system demonstrated success through the seamless integration of image capture, description, and location mapping. An interactive map visualization displayed the captured photos with descriptive popups, making the experience engaging and intuitive. Behind the scenes, a robust backend efficiently managed metadata storage, while the front end offered clear and accessible visualizations.

What Did Not Work

The approach faced several challenges. IP-based geolocation proved to be less precise than GPS, and there was potential latency when synchronizing real-time photo captures with map updates. Additionally, the AR immersion was negligible. The image quality was also a concern, with visible banding and noise artifacts and nighttime captures suffered from excessive colour banding, rendering the photos nearly unusable in low-light conditions.

This prototype showcased the effective union of AI-driven visual descriptions with interactive geolocation mapping. It also highlighted key improvement areas, such as enhancing geolocation precision and image quality under challenging conditions.

[31] GPS-based enhancements / IP-based geolocation: Methods for determining user location

6.1.2.5.Concept 2: Summary

The concept 2 scenario explored prototypes that enable users to spatially organize and interact with personal memories. Prototype 6 introduced a manual approach where users could pin photos and add descriptive labels to a map, reinforcing personal memory links but lacking automated insights. Building on this, Prototype 7 refined the interface using modern web technologies to handle complex spatial data with features like marker clustering and route visualization, setting the stage for future AI and AR enhancements. Prototype 8 integrated AI-generated captions with interactive mapping and webcam capture, streamlining the documentation process and enriching the memory narrative, although it was still limited by a 2D interface. Finally, Prototype 9 merged wearable smart glasses captured photos with real-time AI captions, creating an interactive, location-based memory tool that demonstrated the potential of AI-driven spatial mapping despite challenges with precise geolocation and immersive AR integration.

6.1.3. Concept 3: Real-Time AI Annotation

What if (3):

What if AI-enhanced vision systems provided on-the-fly annotations of our surroundings, offering immediate access to relevant memories as we move through the world?

Scenario (3):

Jake steps out in the morning wearing smart glasses equipped with AI-assisted vision. As he gazes at the bookstore ahead, a subtle overlay flickers, reminding him he once met an old friend there to discuss a must-read novel. When he moves along, a translucent note appears near a lamp post, nudging him to recall the errands he intended to run. He had promised to buy sugar for his grandmother. The system analyzes his surroundings in real time, highlighting spots tied to previous plans or sentimental memories. Privacy concerns arise, of course, and some folks prefer turning the feature off. Yet for individuals like Jake, the relief of not forgetting small tasks or cherished moments is a welcome change. Where typical reminders might fade in a phone's cluttered notifications, these direct overlays keep important bits of life front and center.

Figure 27: An image depicting real time AI annotation

6.1.3.1.Prototype 10: Webcam-LLaVA

Prototype 10 offers an innovative integration of real-time webcam capture with AI-driven scene analysis, blending computer vision and language understanding. It offers an early exploration into enriching memory formation by translating visual scenes into descriptive text using the Large Language and Vision Assistant (LLaVA) model.

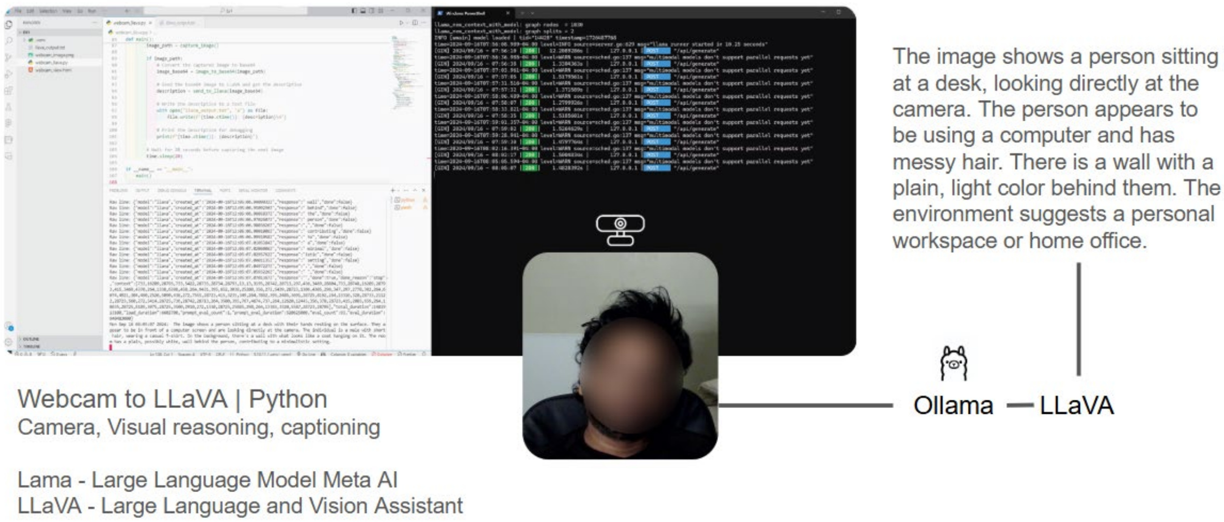

Figure 28: Prototype 10 - Webcam LLaVA

Intent, Impact and Key Takeaway

The intent is to assess how real-time AI-generated text descriptions of scenes could enrich memory formation. The impact is that while automated captions offer immediate context, they remain disconnected from spatial experiences or user interaction. The key takeaway is that although AI-driven descriptions are promising, they require integration with location data or augmented reality to create actionable, memory-reinforcing cues.

The Idea

This prototype aimed to integrate computer vision and language understanding by capturing webcam images and sending them to an LLaVA model (running on Ollama) for real-time scene description. The goal was to explore how AI-generated textual annotations could be combined with captured visual content, potentially aiding memory encoding by connecting environmental imagery to descriptive narratives.

Development

The implementation involved using a Python script that accessed the user's webcam via OpenCV, capturing and saving frames at regular intervals. The script encoded these images and sent them to the locally running Large Language and Vision Assistant (LLaVA) model via an Ollama server, which then returned text descriptions for each image. These descriptions were stored in a text file for later reference. This setup required installing and running Ollama, pulling the LLaVA model, and ensuring stable integration between Python's requests library and the model's API endpoint.

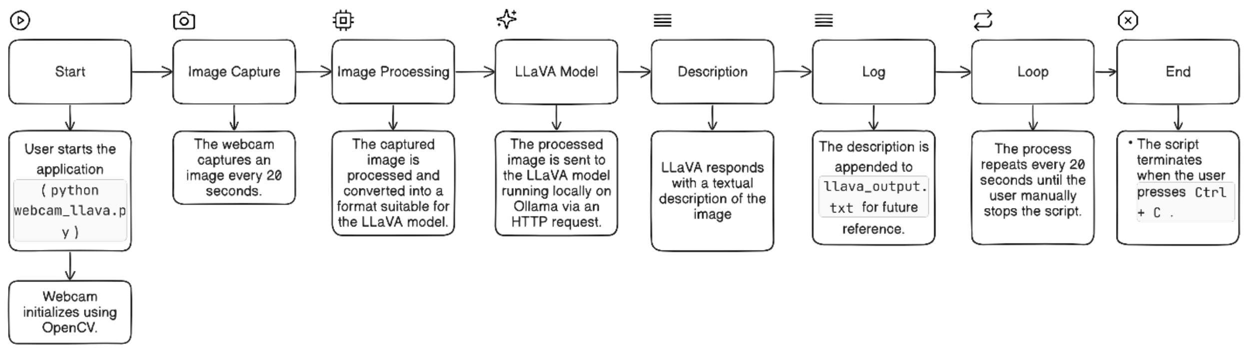

Figure 29: Prototype 10 development workflow

Tech Stack

Python, OpenCV (webcam capture), LLaVA model (vision-language), Ollama (local model hosting)

Reflection

Reflecting on this prototype's process underscored the complexity of bridging hardware input (webcam) and AI-driven interpretation. While the text descriptions provided a promising direction, the experience remained isolated users captured images, received textual output, but had yet to integrate these outputs meaningfully with spatial or AR contexts. Still, it validated the feasibility of on-demand AI scene analysis.

What Worked

The system demonstrated smooth integration between the webcam capture and model inference pipelines, yielding reliable textual output that enriched raw imagery with semantic descriptions. Additionally, the straightforward logging of results enabled effective later review and analysis.

What Did Not Work

The system faced several issues. It lacked direct augmented reality integration and spatial referencing, meaning that the descriptions remained as mere textual logs without any connection to location-based cues. Additionally, interactive features were limited, as users had no opportunity to refine or guide the AI's responses. There were also potential latency issues when capturing and processing images too frequently.

This prototype showcased the potential of integrating live image capture with AI-driven text generation to provide instant semantic context. It also highlighted the need for further development in spatial integration and augmented reality to transform these descriptions into actionable memory aids.

6.1.3.2. Prototype 11: Webcam-LLaMa 3.2 Vision

Prototype 11 offers an innovative approach to integrating local AI-powered scene analysis into everyday contexts by utilizing the Large Language Model Meta AI (LLaMa Vision 3.2[32]) model for detailed, real-time environmental documentation. It paves the way for systematic observation using a multi-dimensional framework that enhances captured imagery with rich, structured insights.

Intent, Impact and Key Takeaway

The intent is to examine how local AI (Large Language Model Meta AI 3.2) driven scene analysis can be integrated into everyday contexts, potentially aiding in environmental documentation. This approach offers a foundation for automatically annotating real world imagery, enabling quick logging and later review of scene details. The key takeaway is that while automated text generation enriches captured visuals with depth, fully harnessing this data requires a more interactive and context aware system, one that might bridge to augmented reality, user control, or real time scene augmentation.

The Idea

This prototype demonstrates how to capture images from a webcam at regular intervals and feed them into a locally hosted LLaMa Vision model for real-time scene analysis. The aim is to explore how AI-generated descriptions can provide structured insights into everyday scenes, using a tiered framework (Kim Vicente's Human Organizational Ladder[33]) for systematic observation. (Vicente, 2004)

Development

The development process begins with capturing 1920x1080 webcam frames using OpenCV. The images are then converted to Base64[34] for HTTP transmission[35] and sent to a local LLaMa

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[32] LLaMa Vision 3.2 (local AI model): Locally hosted Meta AI vision-language model. Available at: https://ollama.com/library/llama3.2
[33] Kim Vicente's Human Organizational Ladder: Framework analyzing systems at multiple levels
[34] Base64: Encoding scheme for converting binary data into text.
[35] HTTP transmission / Requests library: Protocol and Python library for data requests

Vision endpoint for detailed analysis. Responses from this endpoint are read line by line to handle partial data. In addition, the AI analysis is logged to a file with timestamps, and the system captures and analyzes images every 20 seconds.

System Prompt used: "You are an expert image investigator tasked with conducting a structured analysis using Kim Vicente's Human Organizational Ladder. Begin with an overall analysis of the scene, describing the setting, objects, colours, people, and notable details. Then, systematically examine the image through the Physical (size, shape, material), Psychological (information flow, cause-effect), Team (authority, communication, responsibilities), Organizational (culture, structures), and Political (laws, policies, regulations) dimensions. Conclude with critical insights, highlighting significant observations, questions, and areas for deeper exploration - ensuring no section is omitted for a complete analysis."

Sample output: See Appendix C

Tech Stack:

Python, OpenCV, Requests, Base64, Local LLaMa Vision Model (3.2).

Reflection

This integration showed how a local vision-language model could be looped into a simple Python workflow for near-real-time, automated scene analysis. Although the text descriptions offer deeper scene understanding, the current approach remains purely terminal- and file-based, without an interactive or spatial dimension. Future iterations might overlay these descriptions in augmented reality settings or allow for interactive follow-up queries, creating a more immersive and dynamic experience.

What Worked

The script reliably captures clear, high resolution images by using OpenCV. Utilizing the model's prompt, the AI consistently returns scene descriptions broken down by physical, psychological, and other dimensions. Additionally, appending outputs to a text file provides a simple and low friction way to store historical data for review or further processing.

What Did Not Work:

The system encountered several challenges. The generated analysis could not be refined or interacted with in real time. Additionally, the scene descriptions remained detached from the environment, as there was no mechanism linking images or text to specific spatial points. Furthermore, Kim Vicente's Organisation ladder system prompt was not utilized as effectively as expected (Vicente, 2004).

This prototype showcased the potential of local AI to transform simple webcam captures into a nuanced narrative of everyday scenes. It underscored both the promise and the current limitations of automated analysis, setting the stage for future, more interactive and immersive applications.

6.1.3.3.Prototype 12: Webcam-Florence 2 Large Caption

Prototype 12 offers an innovative approach to leveraging Microsoft's Florence 2[36] Large Caption model for near real-time webcam captioning. By integrating live image feeds into ComfyUI[37] it paves the way for enhanced accessibility and memory support tools.

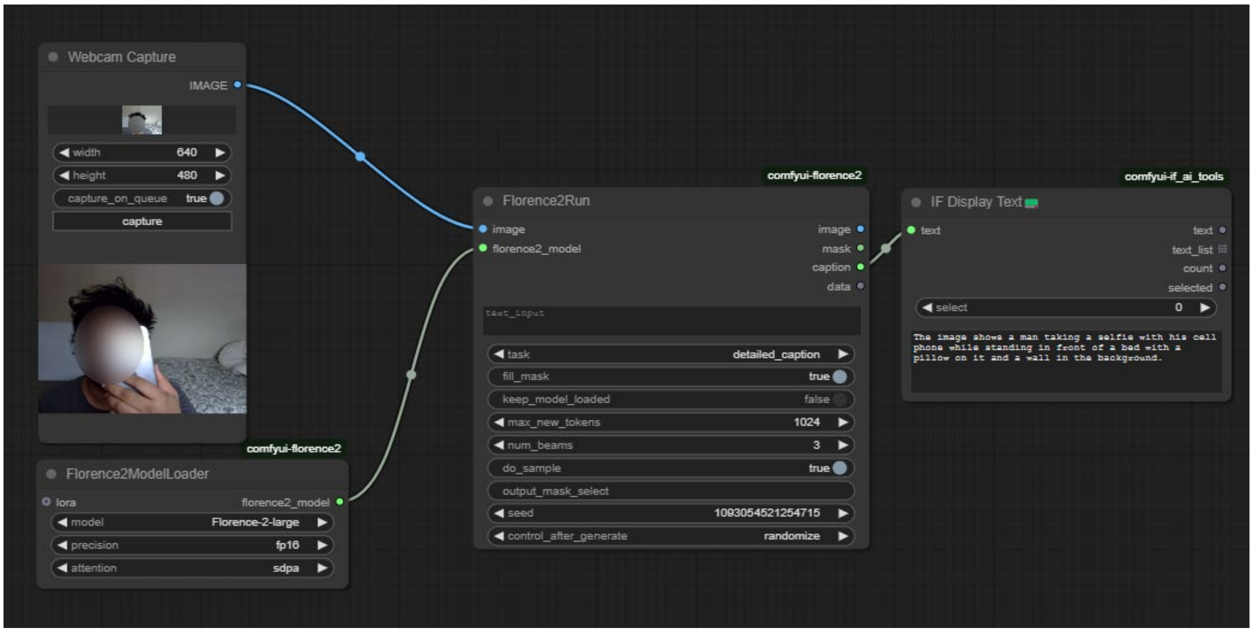

Figure 30: Prototype 12 - Webcam - Florence 2 Large caption

Intent, Impact and Key Takeaway

The intent was to evaluate how Microsoft's Florence 2 Large Caption model (Microsoft/Florence-2-Large · Hugging Face[38], 2025) can generate near real-time captions from a webcam feed within ComfyUI (comfyanonymous, 2023/2025), focusing on both speed and quality for potential memory support tools. The impact of this approach is significant, as it demonstrates a straightforward method for live image captioning that could serve various purposes, including accessibility, logging visual information, or acting as a foundational element

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[36] Microsoft Florence 2 Large (caption model): Microsoft's model for image captioning. Available at: https://huggingface.co/microsoft/Florence-2-large
[37] ComfyUI: Node-based interface for AI tasks and image pipelines. Available at: https://www.comfy.org/
[38] Hugging Face (model repository): Online hub for sharing and hosting AI models. Available at: https://huggingface.co/

for more advanced augmented reality (AR) and large language model integrations. Ultimately, the key takeaway is that Florence 2 Large provides high-quality captions with minimal setup in ComfyUI; however, further work is necessary to seamlessly integrate AR or large language models to enhance interactive capabilities for memory support.

The Idea

This prototype routes a live webcam feed into ComfyUI using its Webcamera Capture node (Seppänen, 2024/2025), then processes the frames through the Florence 2 Large model (downloaded from Microsoft's Hugging Face repository) to generate captions. By leveraging ComfyUI's flexible node system, it becomes possible to explore real-time captioning performance and textual outputs without additional fine-tuning on the model.

Development

For development, ComfyUI was installed and configured on Windows local machine, enabling both standard and custom nodes. The Webcamera Capture node was linked to produce a live image stream, forwarding frames into the Florence 2 nodes. Next, the Florence2ModelLoader node was utilized to automatically download and load the raw Microsoft Florence 2 Large checkpoint, with no fine-tuning applied. Finally, the Florence2Run node was connected to receive frames and output text captions describing the camera feed.

Tech Stack

ComfyUI, Microsoft Florence 2 Large Caption Model, Web camera Capture Custom Node, Florence2ModelLoader & Florence2Run Custom Nodes

What Worked

ComfyUI's node ecosystem facilitated the swift assembly of a working pipeline, from webcam input to caption output. Even without any fine-tuning, Florence 2 Large produced detailed, contextually coherent captions, and its speed was impressive, handling high-resolution frames without major latency.

What Did Not Work

The integration presented certain challenges. The extra step of installing custom caption and webcam nodes proved to be an integration hurdle, complicating the process of achieving a seamless setup. Additionally, there is currently no direct method to combine these real-time captions with AR overlays or LLM-based interactions.

This prototype showcased the effective fusion of advanced captioning model with flexible UI integration. While challenges persist in seamless AR or LLM integration, it emphasizes the potential for further innovation in real-time visual processing.

6.1.3.4.Prototype 13: Frame Vision

Prototype 13 offers an innovative approach to blending augmented reality with AI-driven memory logging, harnessing smart glasses and a vision-language model for seamless, hands-free image capture. It transforms everyday experiences into enriched data points, automatically tagging images with context and location to build continuous, meaningful memory logs.

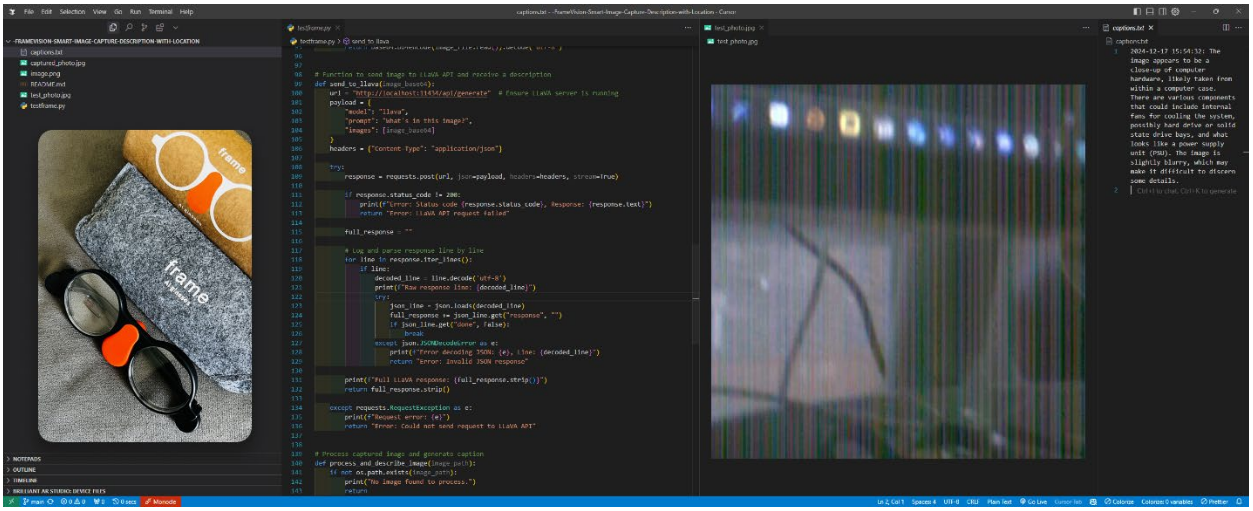

Figure 31: Prototype 13 - Frame vision

Intent, Impact and Key Takeaway

The intent is to test wearable capture using smart glasses (Brilliant Frames) combined with AI-driven descriptions for real-time, location-based memory logging. This approach impacts users by enabling hands-free image capture and providing automatic context descriptions, thereby lowering the interaction burden; however, imprecise geolocation can reduce the accuracy of the captured data. The key takeaway is that seamless wearable capture has the potential to strengthen continuous memory building, and further improvements in location tracking and AR overlays could enhance recall even more.

The Idea

Frame Vision integrates Brilliant Labs Frame smart glasses with the LLaVA Vision-Language model to deliver smart image capturing paired with geolocation and textual descriptions. The system captures moments in real time, extracts location data via IP-based services, and generates contextualized descriptions using a locally hosted LLaVA model. This combination of augmented reality hardware and AI enables users to log spatially enriched memories seamlessly.

Development

The project utilized Python to orchestrate communication between the Frame smart glasses and the LLaVA model. Captured photos were processed locally using Ollama's API to generate meaningful textual descriptions. Geolocation was retrieved through IP-based services and appended to captions with timestamps. Despite its robust functionality, achieving smooth Bluetooth pairing with the Frame and optimizing the API communication required significant debugging.

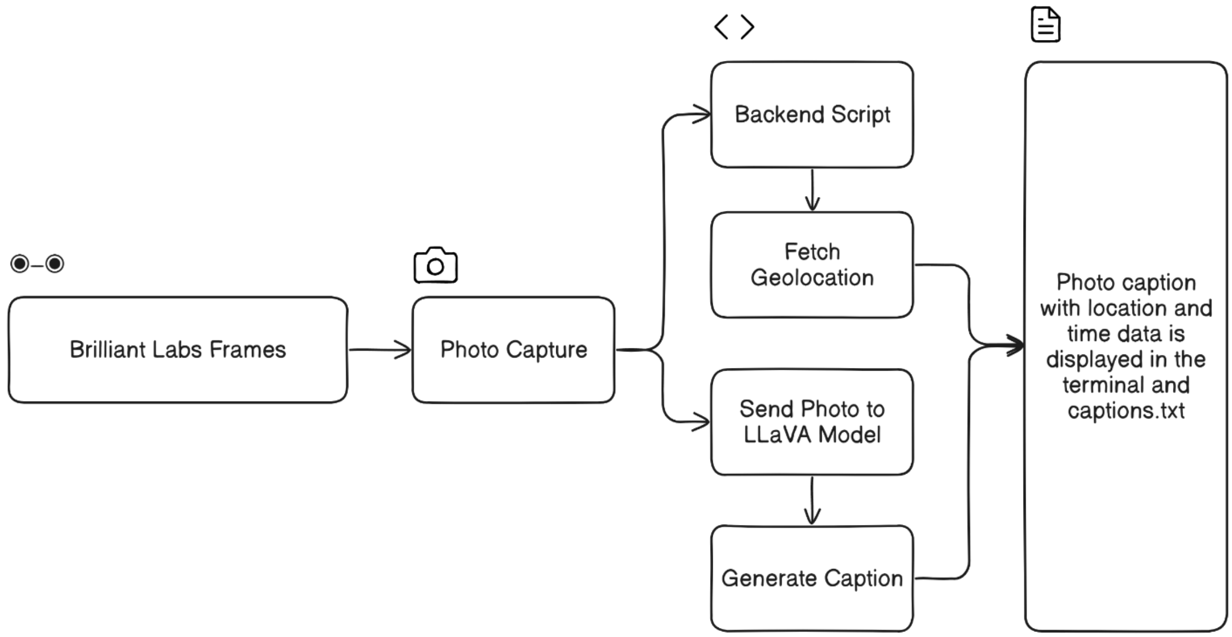

Figure 32: Prototype 13 development workflow

Tech Stack:

Brilliant Labs Frame (smart glasses), Python, LLaVA (Large Language and Vision Assistant), Ollama (model hosting), IP-based geolocation

Reflection

The system succeeded in delivering spatially and semantically rich image logs, demonstrating the feasibility of combining AR hardware with AI-driven descriptions. However, the reliance on

IP-based geolocation limited precision in some scenarios. While this proof-of-concept showed promise, further iterations could include GPS integration for higher accuracy and advanced interactivity for refining generated captions.

What Worked

Reliable image capture was achieved with Brilliant Frame smart glasses, complemented by accurate textual descriptions of the captured images. The system also efficiently logged timestamps, descriptions, and geolocations, ensuring a comprehensive record of the events.

What Did Not Work

Limited precision of IP-based geolocation hindered accurate positioning, and there were occasional delays in API responses during high-frequency image captures. Additionally, AR immersion was negligible, while the image quality suffered due to visible banding and noise artifacts. Nighttime captures were particularly problematic, as excessive colour banding rendered photos nearly unusable in low-light conditions.

This prototype showcased the promise of wearable technology to deliver spatially enriched and semantically detailed image logs despite challenges with geolocation precision. The insights gained pave the way for further refinements, such as improved GPS integration and enhanced AR immersion, to elevate user experience even further.

6.1.3.5. Concept 3: Summary

The concept 3 scenario explored prototypes that utilized real-time webcam capture and wearable devices with AI-driven scene analysis to enrich memory formation by translating visual scenes into descriptive text. Prototype 10 integrated live webcam capture with the LLaVA model to generate immediate textual descriptions, highlighting the potential of automated context while noting the need for spatial integration. Prototype 11 utilized a locally hosted LLaMa Vision 3.2 model to provide structured, detailed environmental analyses based on a tiered observation framework, although it remained disconnected from interactive spatial elements. Prototype 12 demonstrated near real-time captioning using Microsoft's Florence 2 Large Caption model in ComfyUI, proving high-quality, live image descriptions with room for improved AR or LLM integration. Finally, Prototype 13 combined wearable smart glasses with AI-generated descriptions for hands-free, continuous memory logging enriched with geolocation data despite challenges with location precision and image quality under varied conditions.

6.1.4. Concept 4: Voice as a Memory Partner

What if (4):

What if voice assistants evolved into true cognitive partners, actively prompting, reinforcing, and contextualizing our memories during daily life?

Scenario (4):

Tanya's morning begins with a gentle voice in her ear, her AI partner, that has grown more interactive over the past year. While making coffee, the assistant softly references a recent chat Tanya had with her cousin, prompting her not to forget the call she'd promised. On her commute, the assistant recalls a past musical performance Tanya attended, suggesting a playlist that might spark fresh ideas for an upcoming project. The conversations flow freely, almost like banter with a close friend who remembers every key moment. At work, it chimes in again when she's stuck on a problem, recalling an old brainstorming technique she used once with success. Though some worry about depending too heavily on these continuous prompts, many find that these voice-based nudges enrich day-to-day decision-making. In this new setting, the subtle guidance of a digital companion feels more personal than ever.

Figure 33: An image depicting Voice as a Memory Partner

6.1.4.1.Prototype 14: AI Voice Assistant with OpenAI GPT-3.5 Turbo

Prototype 14 offers an innovative, hands-free conversational AI experience that utilizes OpenAI's GPT-3.5-turbo for speech-based interaction. It aims to explore how auditory interfaces can support memory processes by reinforcing recall through verbal cues.

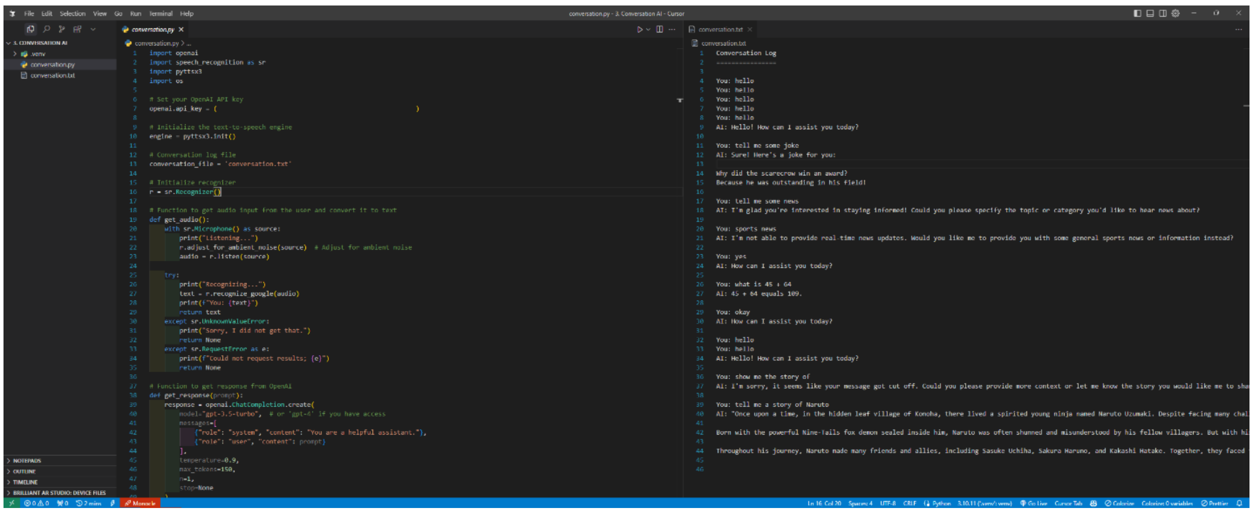

Figure 34: Prototype 14 - AI Voice Assistant with OpenAI GPT-3.5 Turbo

Intent, Impact and Key Takeaway

The intent was to determine whether conversational, hands-free AI could assist in memory processes through speech-based interaction. The impact was that while voice interaction creates a more personal and immediate channel of communication, it lacks the spatial or visual cues that contribute to deeper memory embedding. The key takeaway is that conversational AI might enhance recall when integrated with memory cues, and combining it with spatial or augmented reality elements could provide a richer, multimodal memory experience.

The Idea

This prototype focused on creating a hands-free, conversational AI experience. Rather than relying on typed input, users could speak directly to the system and receive spoken responses. By leveraging OpenAI's GPT-3.5-turbo model, the prototype aimed to provide fluid, contextually relevant dialogue. Meanwhile, the inclusion of speech-to-text and text-to-speech[39] functionalities meant that users could interact naturally, as though holding a conversation with a virtual assistant. The concept was to explore how an auditory interaction model could support memory tasks, such as prompting users with reminders or reinforcing recall through verbal rehearsal.

Development

The development process began by implementing a Speech-to-Text component using the Speech Recognition library to capture voice input from the user's microphone and convert it into text. This was followed by integrating the OpenAI GPT-3.5-turbo model for AI text generation, which produces contextually relevant and intelligent responses based on the input. To complete the interactive experience, the Text-to-Speech functionality was implemented using the pyttsx3[40] library, allowing the model's responses to be read out loud and creating a fully auditory feedback loop. Finally, conversation logging was established by storing transcripts of the entire conversation in a text file, which facilitates the review and analysis of interaction patterns and response quality.

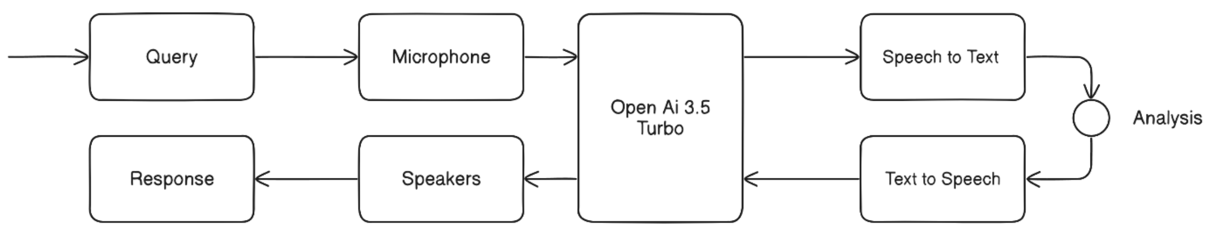

Figure 35: Prototype 14 development workflow

No AR or map-based integration was implemented here; the focus remained squarely on refining a natural voice interface and seeing if an auditory assistant might complement or enhance memory practices (e.g., by verbally iterating over memorized lists or concepts).

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[39] Text-to-Speech: Converts written text into spoken words

[40] pyttsx3 (text-to-speech): Python library for converting text to spoken audio. More information at: https://pypi.org/project/pyttsx3/

Tech Stack:

Python, OpenAI GPT-3.5 Turbo[41], Speech-to-Text (SpeechRecognition[42]), Text-to-Speech (pyttsx3)

Reflection

Reflecting on this prototype, it became apparent that incorporating voice interaction introduced a more personal and immediate dimension to AI-driven memory support. Users could, in theory, rehearse information, ask follow-up questions, or request reminders in a more natural manner than typing might allow. While this approach did not provide spatial or visual memory cues, it explored another sensory channel—hearing—which might reinforce memory through vocal repetition and auditory feedback.

What Worked

Voice input and output contributed significantly by making the AI feel more like a personal assistant rather than just a tool, thereby fostering engagement and potentially improving recall through conversational rehearsal. Additionally, GPT-3.5-turbo's ability to maintain context across multiple turns facilitated nuanced follow-up questions and iterative learning dialogues. Moreover, the conversation log proved invaluable by allowing users to review past interactions, track progress, and identify which queries or responses were most effective in enhancing their memory.

What Did Not Work

Several challenges emerged during development. The speech-to-text accuracy often degraded in noisy environments, limiting the system's reliability. Additionally, the absence of spatial or visual cues made it difficult to form strong mental associations compared to AR-based or map-based prototypes. Although the conversational capabilities were robust, the system was not explicitly optimized for mnemonic strategies, potentially reducing its direct impact on enhancing

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[41] OpenAI GPT-3.5 Turbo: Advanced text-generation model from OpenAI. Available at: https://openai.com/api/

[42] SpeechRecognition (Python library): Converts microphone input into text. More information at: https://pypi.org/project/SpeechRecognition/

memory retention beyond simple verbal repetition. Lastly, the GPT-3.5 conversational AI has become outdated, with newer real-time AI systems offering improved conversational abilities and access to the internet for added context.

This prototype showcased the potential of voice-enabled AI to create a more personal and engaging memory support system despite the absence of spatial cues. Its exploration of auditory interactions opens up possibilities for further enhancements by integrating additional multimodal elements.

6.1.4.2.Concept 4: Summary

The concept 4 scenario explored prototype that utilize voice-based conversational AI to support memory through auditory cues. Prototype 14 offers a hands-free experience by integrating OpenAI's GPT 3.5 turbo with speech-to-text and text-to-speech functionalities, allowing users to interact naturally with a virtual assistant that logs conversations for later review. Designed to reinforce recall through verbal rehearsal and immediate feedback, the system demonstrates how conversational AI can create a personal, engaging interface; however, it lacks the spatial and visual cues necessary for deeper mnemonic embedding, and its performance can be hindered by noisy environments and outdated AI capabilities.

6.1.5. Concept 5: 3D Representation of Memory

What if (5):

What if AI could convert our thoughts and descriptions into fully realized 3D objects, allowing us to explore memories as interactive, spatial constructs?

Scenario (5):

On a quiet evening, Rosa takes a seat in her favourite park and focuses on a childhood memory: her father teaching her to tie shoelaces. Seconds later, a 3D hologram appears at the foot of a bench, illustrating the exact steps. The system allows her to rotate and enlarge the scene, even pausing it to savour details she forgot. Artists embrace this invention to shape conceptual models, creating tangible shapes out of their roughest sketches. Teachers discover its value in crafting detailed lessons out of a student's imagination, turning abstract thoughts into visual aids on the fly. Critics wonder if these creations might blur the line between recollection and fantasy, but folks like Rosa see them as a heartfelt way to hold treasured stories in plain sight. In just a few years, the act of remembering can bring entire scenes to life with a single request.

Figure 36: An image depicting 3D Representation of Memory

6.1.5.1.Prototype 15: Text to 3D

Prototype 15 offers an innovative approach to transforming natural language into detailed 3D models, reducing the dependency on specialized skills. It utilizes rapid AI-driven techniques to create personalized mnemonic objects that enhance creative workflows.

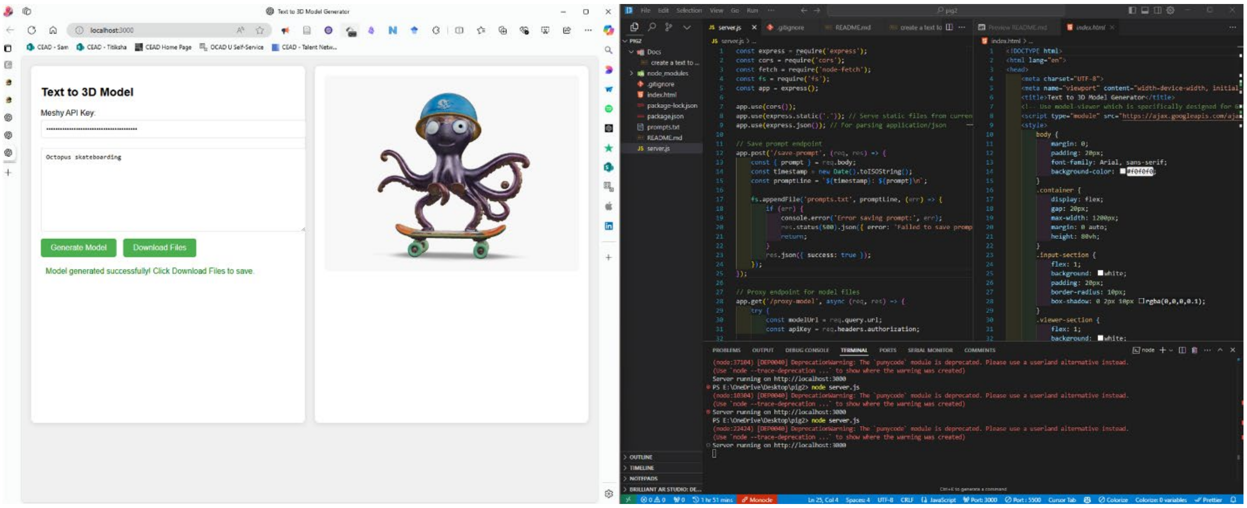

Figure 37: Prototype 15 - Text to 3D 1

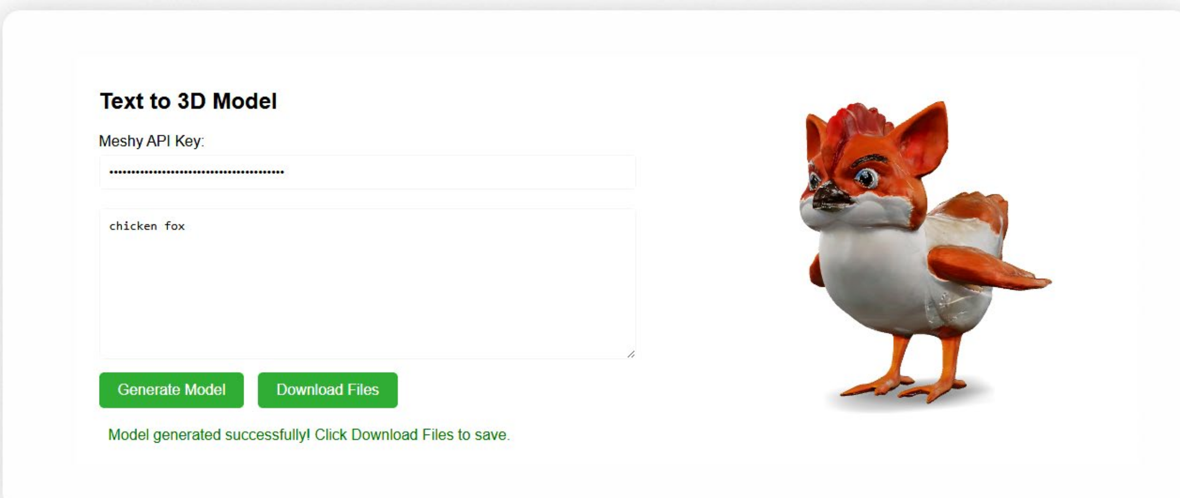

Figure 38: Prototype 15 - Text to 3D 2

Figure 39: Prototype 15 - Text to 3D 3

Intent, Impact and Key Takeaway

The intent is to evaluate the value of rapid AI-generated 3D models as personalized mnemonic objects. Quick model generation reduces barriers to creating custom memory cues, although the longer rendering times can hinder on-demand usage. The key takeaway is that automated 3D asset creation has the potential to personalize spatial memory, and future improvements toward real-time or near-instant conversions could significantly enhance AR memory tools.

The Idea

This project explores the innovative potential of AI-driven content creation via the Meshy.ai[43] API. By harnessing Meshy.ai's capabilities in converting natural language into 3D geometry, the project enables users to transform plain-language prompts into detailed 3D models. The API focuses on simplifying the creation process, empowering designers, students, and hobbyists to produce high-quality 3D content without requiring specialized modelling expertise.

Development

The application uses a Node.js[44] backend with a vanilla JavaScript[45] frontend and manages a two-stage model generation process, starting with an initial preview and culminating in a texture-

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[43] Meshy.ai (text-to-3D service): API turning text prompts into 3D models. Available at: https://www.meshy.ai/
[44] Node.js (backend runtime): JavaScript runtime for server-side scripting. Available at: https://nodejs.org/en
[45] Vanilla JavaScript: Plain JS code without additional frameworks

refined final output while tracking progress in real time. It incorporates secure client-side API key management to protect Meshy.ai credentials and user data, and real-time progress tracking provides immediate feedback during model generation. Additionally, dynamic file naming automatically tags output files with user prompts for organized storage. A custom proxy server handles Cross-Origin Resource Sharing[46] (CORS) complexities to ensure uninterrupted data flow, and Google's Model Viewer is integrated as a GLB[47] viewer to showcase the 3D results directly in the browser.

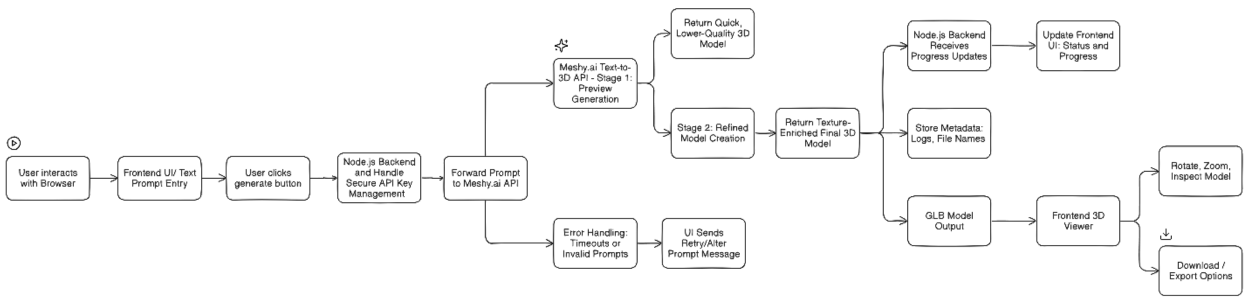

Figure 40: Prototype 15 development workflow

Tech Stack

Meshy.ai API (text-to-3D), Node.js (backend), JavaScript (frontend), Google Model Viewer[48] (3D viewer)

Reflection

The project highlights AI's potential to transform creative workflows, enabling quick 3D model development from conceptual text alone. The two-stage generation strategy effectively balances speed and quality.

What Worked

The approach proved successful in several areas. There was seamless API integration with Meshy.ai's Text to 3D service, which facilitated smooth communication between systems. Real

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[46] CORS (Cross-Origin Resource Sharing): Browser policy for sharing resources across domains
[47] GLB format / GLTF files: Common 3D file types for geometry and textures
[48] Model Viewer (Google): Web component for rendering 3D models in browsers. Available at: https://modelviewer.dev/

time model previews were available directly within the browser, enhancing engagement. The system also featured robust error handling and clear status notifications, ensuring that any issues were promptly communicated. A user centric interface emphasized clarity and simplicity, making it straightforward to navigate. Additionally, a prompt logging system was implemented to allow for the easy retrieval of generation history.

What Did Not Work

The system faced several challenges. There were limited customization options for refining texture and geometry and no batch processing available for bulk model generation. In addition, there was a lack of advanced 3D viewer controls for deeper model exploration and missing support for additional 3D formats beyond GLB. The absence of local caching resulted in slower loading times, and the long generation time, which can take around five minutes per model, further hampered efficiency.

This prototype showcased the potential of AI in generating custom 3D assets, significantly simplifying the process. Despite challenges like longer rendering times, it lays a strong foundation for future advancements in real-time AR memory tools.

6.1.5.2. Concept 5: Summary

The concept 5 scenario explored prototype that transform natural language into detailed 3D models to serve as personalized mnemonic objects. Prototype 15 leverages the Meshy.ai API with a Node.js backend and vanilla JavaScript frontend to convert plain-text prompts into 3D geometry, enabling rapid creation of custom memory cues without requiring specialized modeling skills. Although the approach offers real-time model previews directly in the browser, challenges such as longer rendering times and limited customization options highlight the need for further improvements. Overall, this prototype demonstrates the potential for AI-driven 3D asset generation to enhance creative workflows and spatial memory tools, with future iterations aiming for near-instant conversions and richer viewer controls.

6.1.6. Final Prototype

Development of various prototypes, ranging from A-Frame's purely virtual 360-degree environments to Adobe Aero's real-world AR anchoring and Niantic Lightship's ARDK[49] for precise, persistent placement, highlighted the importance of merging immersive visuals with physical spaces. Early explorations, including Prototypes one to five, confirmed that location-based overlays and tangible 3D objects significantly enhance mnemonic impact, particularly when users can walk around, manipulate objects, or revisit meaningful places in augmented reality. Subsequent advances in real-time AI annotation, seen in Prototypes ten to thirteen, demonstrated how instant contextual captions and scene analyses further enrich memory cues. Meanwhile, the Text-to-3D[50] explorations in Prototype Fifteen showed that the automated generation of personalized 3D models could be a crucial element in creating dynamic, spatially anchored memory aids.

These insights directly influenced the final prototype, which integrates the core ideas behind scenarios one, three, and five. By overlaying location-specific memory triggers onto physical scenes, users experience immersive visual cues, reinforcing the memory recall process seen in scenario one. Real-time AI annotation provides on-the-fly guidance and reminders similar to scenario three, while the system's ability to instantly generate or modify 3D memory objects aligns with scenario five, resulting in a technically functional prototype that seamlessly bridges all three scenarios to support deeper, more intuitive recall.

The final prototype addresses the Immersive Spatial Experiences scenario, the Real-Time AI Annotation scenario, and the 3D Representation of Memory scenario.

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[49] ARDK (Niantic's AR Development Kit): Framework for creating AR with Niantic Lightship. Available at: https://lightship.dev/docs/ardk/
[50] Text-to-3D: AI method for generating 3D objects from text prompts

6.1.6.1.Prototype 16: Mind Palace XR

Prototype 16 showcases the transformative integration of multiple AI services, converting live real-world views into interactive 3D memory cues. It harnesses advanced vision, language, and 3D model generation technologies to create a dynamic, world-scale memory palace in real time.

Figure 41: An image depicting Memory Palace technique with Mind Palace XR app

Intent, Impact and Key Takeaway

The intent is to transform real world views into AI generated 3D cues that enable the immediate construction of a world scale “memory palace.” By integrating multiple AI services such as LLM, vision, and text to 3D within an AR app, this approach shows promise for immersive memory reinforcement. The key takeaway is that converting captured scenes into 3D memory cues in real time marks a compelling step toward dynamic, context rich memory augmentation, although further optimization is required to achieve a seamless experience.

The Idea

Mind Palace XR is an innovative Unity-based application that transforms your real-world surroundings into interactive 3D memory aids. The application captures what you are looking at through your device’s camera and employs advanced AI technologies to create a personalized memory palace at world scale. By associating information with these interactive 3D models, users can utilize spatial memory techniques for better information recall, effectively converting everyday scenes into memorable spatial cues.

Development

The application uses a head mounted display, such as Meta Quest 3's camera system, to capture the live environment. The captured image is processed through Google's Gemini[51] Vision API to generate a detailed context aware description of the scene. This textual description is sent to FalAI to produce a stylized 2D image that offers an artistic interpretation of the captured view. The resulting 2D image is then converted into a detailed 3D model via StabilityAI's[52] Text to 3D Model API. Finally, the 3D model is integrated into the augmented environment using the GLTFast[53] package, ensuring that position and scale are automatically optimized for intuitive spatial placement. Each step in this pipeline operates seamlessly in real time and includes comprehensive error checking with graceful handling of any failed generations, while the generated models are locally stored and organized with timestamps to build a persistent memory palace.

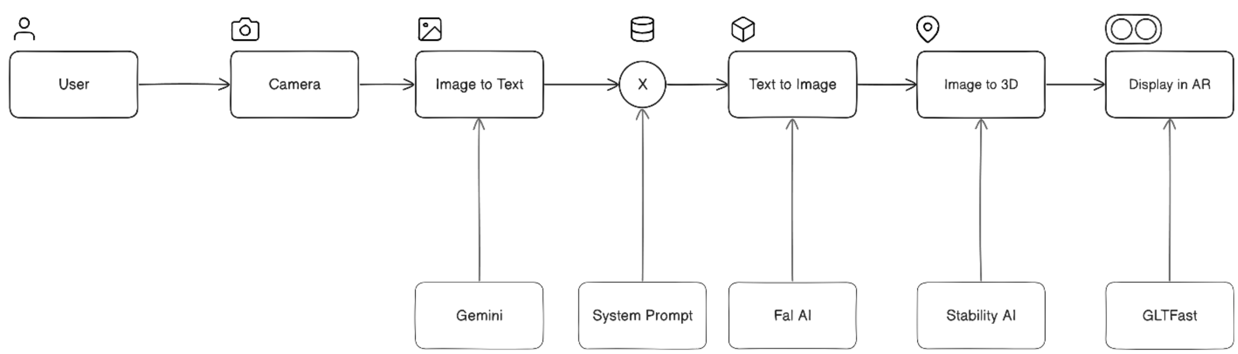

Figure 42: Final Prototype Development Workflow 1

[51] Gemini Vision API (Google): API for advanced scene understanding. Available at: https://aistudio.google.com/
[52] StabilityAI (text/2D-to-3D APIs): AI services for generating images or 3D objects. Available at: https://stability.ai/stable-3d
[53] GLTFast (Unity package): Plugin for fast loading of GLTF/GLB models in Unity. More information at: https://docs.unity3d.com/Packages/com.unity.cloud.gltfast@6.0/manual/index.html

Figure 43: Launch the app

Figure 44: Splash screen appears

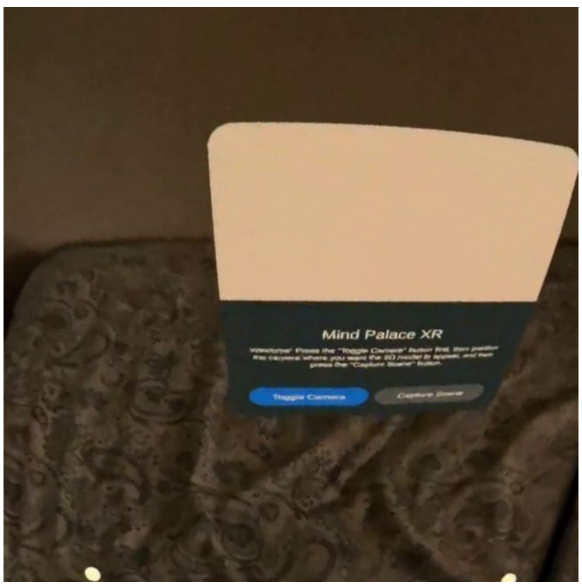

Figure 45: Camera Toggle and capture panel appears

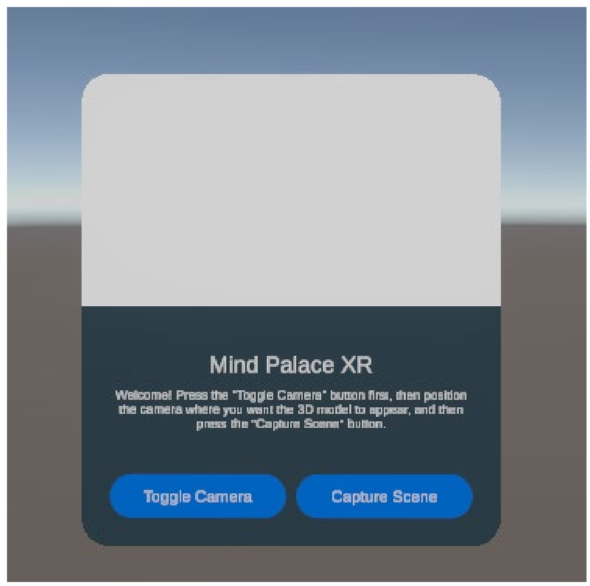

Figure 46: Clear view of the Camera toggle and capture panel

Figure 47: Click Toggle camera

Figure 48: Allow permission to access camera

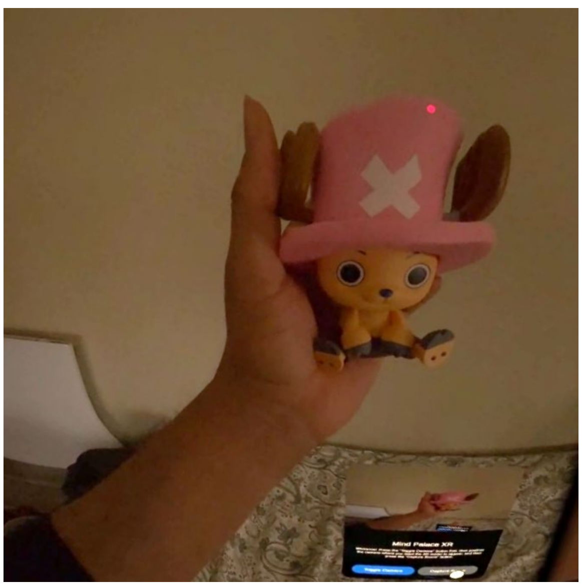

Figure 49: Look at a object/ place/ event, etc and press capture

Figure 50: A 3D model appears based on a system prompt

Video Demo:

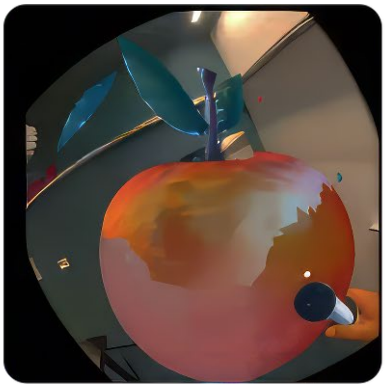

Figure 51: Video Demo of the app in Indoors and Outdoors

Video Demo Indoors 1: https://vimeo.com/1077305128

Video Demo Indoors 2: https://vimeo.com/1077305174

Video Demo Outdoors: https://vimeo.com/1077305210

- Capture the live environment using Meta Quest 3's camera system
- Process the image with Google's Gemini Vision API for a detailed scene description
- Generate a stylized 2D image using FalAI[54]
- Convert the 2D image into a detailed 3D model via StabilityAI's API
- Integrate the 3D model into the augmented space with optimized placement using GLTFast
- Operate in real time with error checking and local storage of models

[54] FalAI: AI service to generate stylized 2D images. Available at: https://fal.ai/

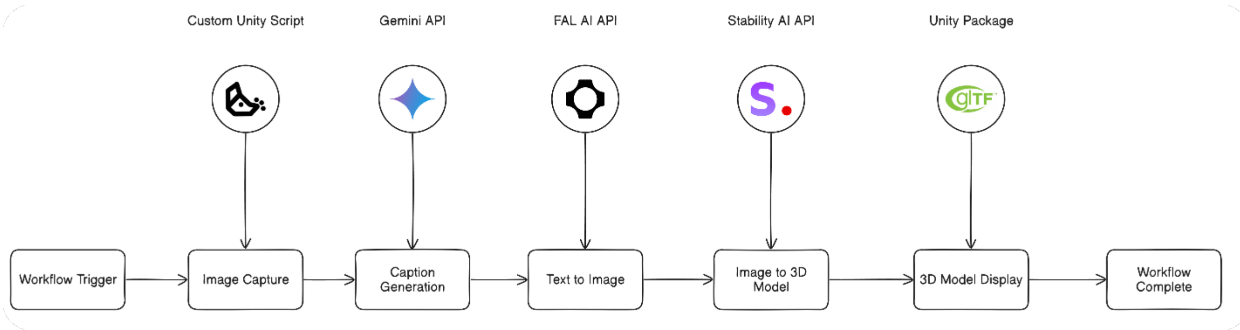

Figure 52: Final Prototype Development Workflow 2

Development Environment

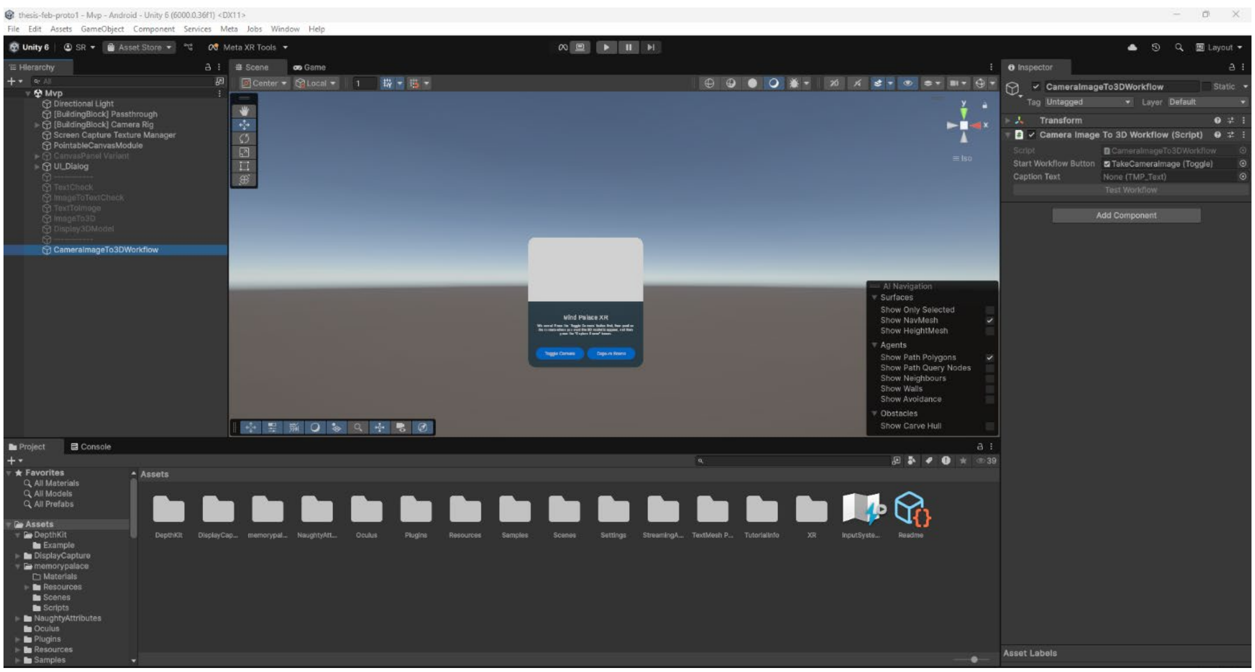

Figure 53: Unity 6 with Meta All in one SDK

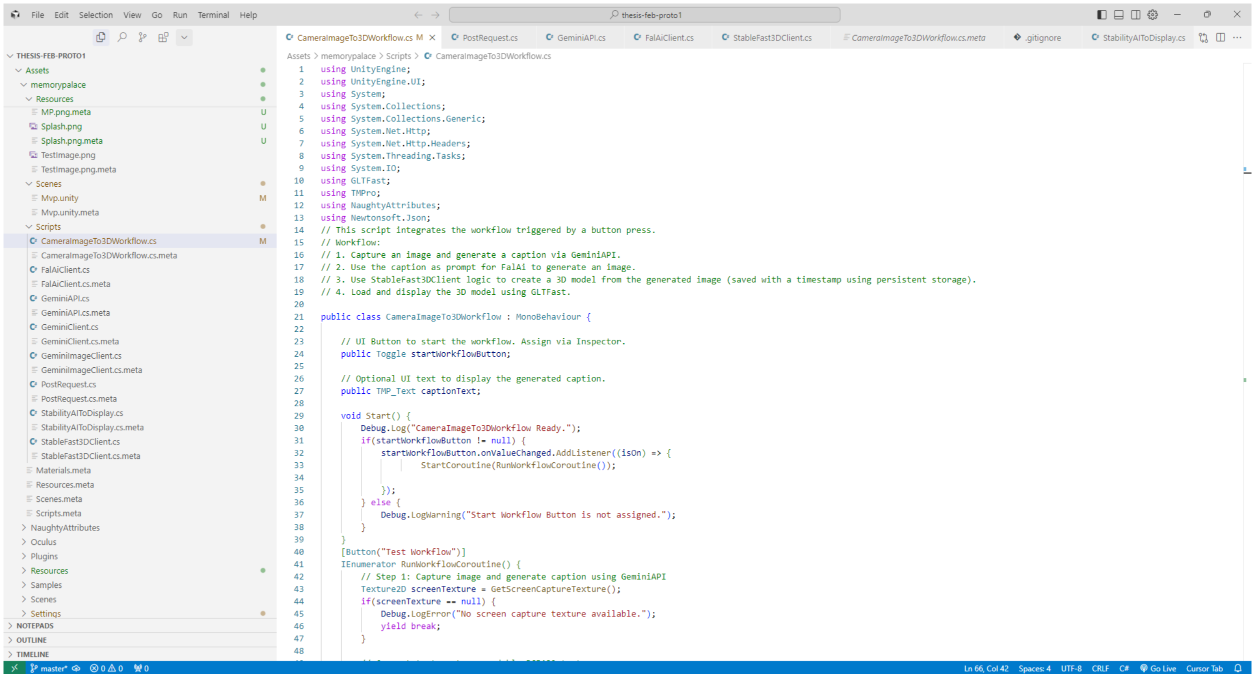

Figure 54: Cursor IDE for custom script development

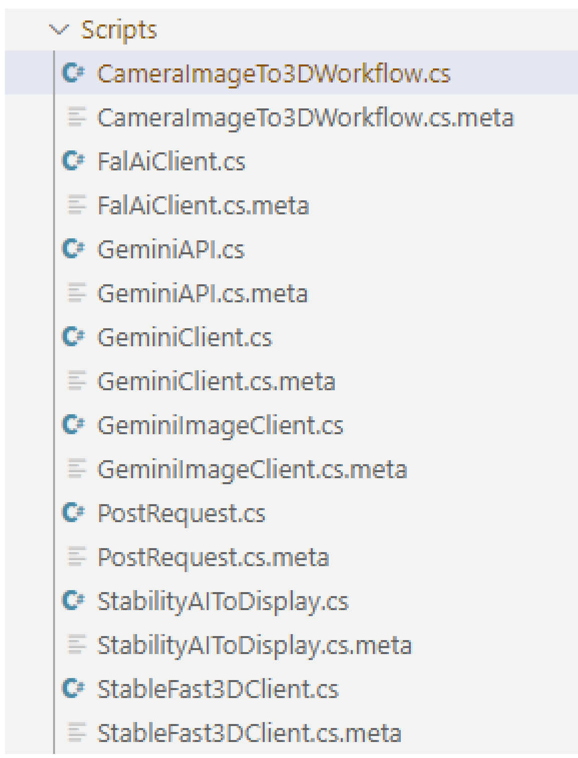

Figure 55: Custom Scripts developed.

Tech Stack

Unity (core engine), Meta Quest 3 (HMD[55] camera), Google Gemini Vision (scene description), FalAI (stylized 2D images), StabilityAI (text/2D-to-3D), GLTFast (3D importing)

Reflection

Mind Palace XR transforms real-world scenes into spatially anchored 3D models. It utilizes Vision AI for real-time scene analysis to generate captions, FluX Image Generation AI to convert captions into 2D images, and Stable fast 3D to transform 2D images into 3D models. This prototype demonstrates the potential of merging immersive 3D models with augmented reality to enhance memory recall. However, further optimization is needed to ensure seamless performance, richer user interactivity, and improved conversational AI and mapping features.

The current prototype lacks support for audio/speech processing and web interfaces while relying on multiple AI APIs for different tasks. The ideal system envisions a multimodal AI that seamlessly integrates memory encoding and retrieval through both visual and speech-based interactions. As AI models advance to better handle the physical world, this system ensures balanced support for both audio/speech and visual interfaces, creating a more intuitive and immersive memory augmentation experience.

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[55] HMD (Head-Mounted Display): Wearable device displaying visuals near the eyes

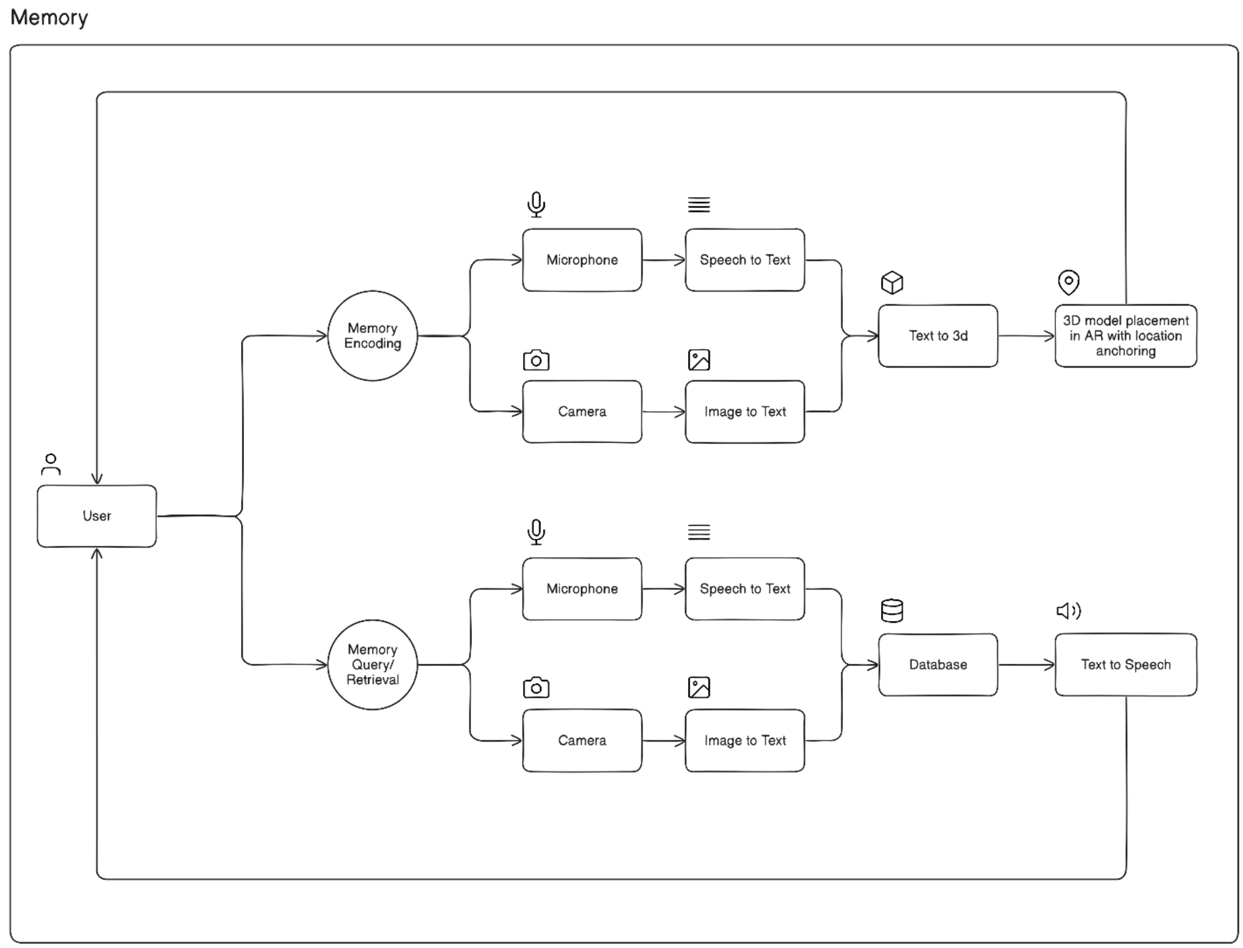

Figure 56: Ideal System: Memory encoding and retrieval

What Worked

Advanced head mounted device camera integration enabled real-time capture of the environment, laying the foundation for contextual memory cues. AI-powered scene analysis, through Google's Gemini API, provided detailed and context-aware descriptions that enhanced scene understanding. In addition, FalAI and StabilityAI were effective in converting textual descriptions into compelling 2D and 3D representations, respectively. Although accessing the camera posed challenges, successful integration was achieved using the QuestDisplayAccessDemo[56] repository.

What Did Not Work

Performance bottlenecks emerged during real time processing of multi step AI integrations, occasionally resulting in latency, particularly when handling multiple API processes. There were limited customization options available for refining texture and geometry, and advanced 3D viewer controls such as grab interaction for deeper model exploration were lacking. Additionally, integrating real time conversational AI proved challenging due to the complexity of its implementation, and efforts to incorporate location history along with a web interface for viewing or editing paths or locations via on device GPS were not successful.

This prototype showcased the seamless integration of AI services and augmented reality to convert everyday scenes into interactive memory aids. Despite performance challenges, it paves the way for more refined and immersive memory augmentation experiences.

[56] QuestDisplayAccessDemo: GitHub repo enabling camera access on Quest devices. Available at: https://github.com/trev3d/QuestDisplayAccessDemo

6.1.6.2. Final Prototype Summary

The Final prototype, Mind Palace XR, represents the culmination of integrating immersive spatial experiences, real-time AI scene analysis, and rapid text-to-3D model generation into a single AR application. By capturing live real-world views using Meta Quest 3's camera, the system utilized Google's Gemini Vision API to generate detailed, context-aware descriptions, which are then interpreted by FalAI into 2D images and further transformed into interactive 3D models via StabilityAI's Image-to-3D API. These models are seamlessly integrated into the augmented space using GLTFast, creating a dynamic, world-scale "memory palace" that enables users to anchor and recall memories through spatial cues. Although performance bottlenecks, limited customization options, and challenges in advanced interactive controls persist, the prototype showcases the promising potential of merging multiple AI services to enhance memory recall in an immersive, real-time AR experience.

6.2.Summary

The prototypes progressively evolved from early explorations of immersive 360° environments and simple AR overlays to advanced systems that combine real-time scene analysis, voice interaction, and AI-driven 3D model generation. Initial efforts focused on anchoring memories in virtual and augmented settings, such as using A-Frame for 360° imagery, Adobe Aero for physical placements, and ShapesXR for mixed reality mock-up interactions. Later iterations introduced spatial memory management through interactive mapping and wearable devices, with AI enhancements like automated image captioning (Webcam-LLaVA, Webcam-Florence) and voice-assisted memory cues (using GPT 3.5 turbo). Additionally, converting natural language into personalized 3D models via the Meshy.ai API further demonstrated the potential for customized mnemonic 3D objects, setting the stage for more complex integrations.

The Final prototype, Mind Palace XR, represents the culmination of these efforts by seamlessly merging immersive spatial experiences, real-time AI scene analysis, and rapid text-to-3D model generation into a single augmented reality application. Capturing live real-world views using the Meta Quest 3, the system processes scenes with Google's Gemini Vision API, transforms descriptions into stylized 2D images with FalAI, and then converts these into interactive 3D models via StabilityAI's Image-to-3D API. Integrated into the augmented space using GLTFast, this dynamic "memory palace" enables users to anchor and recall memories through spatial cues. Despite challenges like performance bottlenecks and limited customization, Mind Palace XR highlights the promising potential of combining multiple AI services to create immersive, context-rich memory augmentation experiences.

The prototypes demonstrated overlapping functionalities with applied memory enhancement techniques discussed earlier (section 3.2.8). Specific features common to both prototypes and these memory enhancement methods are compared in Table 8 and Table 9. The table further highlights areas where functional similarities occur between prototype designs and applied techniques. This analysis provides clarity on the extent of overlap, enabling streamlined refinement in future developments.

	Story Narrative Technique	Dual Coding	Retrieval Practice	Keyword Method	Peg Word System	Elaborative Rehearsal	Chunking and Organisation	Mnemonic Devices	Method of Loci
Prototype 1		■						■	■
Prototype 2	■	■						■	■
Prototype 3		■						■	■
Prototype 4		■						■	■
Prototype 5		■						■	■
Prototype 6		■					■		■
Prototype 7		■					■		■
Prototype 8		■				■	■		■
Prototype 9	■	■				■	■		■
Prototype 10		■							
Prototype 11		■							
Prototype 12		■							
Prototype 13		■							
Prototype 14			■			■			
Prototype 15		■						■	
Prototype 16	■	■						■	■

Table 8: Prototypes overlapping functionalities with memory enhancement techniques 1

	Nootropics	Physical Activity and Sleep	Visual Imagery	Spaced Repetition	Association (Bizarre Visuals)	Name-Face Associati	Rhymes and Songs	Acronyms and Acrostics	Aboriginal Memory Techniques	Concept Mapping
Prototype 1										
Prototype 2										
Prototype 3										
Prototype 4										
Prototype 5										
Prototype 6										
Prototype 7										
Prototype 8										
Prototype 9										
Prototype 10										
Prototype 11										
Prototype 12										
Prototype 13										
Prototype 14										
Prototype 15										
Prototype 16										

Table 9: Prototypes overlapping Functionalities with memory enhancement techniques 2

7. Evaluation

7.1. Introduction

This work is evaluated using multiple approaches. Table 10 and Table 11 presents a descriptive analysis guided by literature-based criteria, while Table 12 to 16 showcases subjective assessments that trace the progression of prototypes from early AR concepts to AI-driven features. By examining criteria like functionality, context awareness, and personalization, the descriptive evaluation highlights comparative strengths and gaps. Concurrently, the subjective evaluation reveals that emphasizing immersion, proactive assistance, and hands-free logging. Together, these methods provide a holistic view of how XR and AI elements can enhance memory support and user engagement. They reveal both areas of promise and points for further refinement.

7.2. Descriptive Evaluation Using Literature-Based Criteria

This descriptive evaluation offers a comparative analysis of sixteen prototypes using ten criteria (Functionality, Adaptability, Context Awareness, Personalization, Ease of Correction, Proactive Assistance, Multi Modal Interaction, Immersion Levels, Presence, and Attention and Flow). Some of these criteria are explicitly established, while others are inferred from key papers in the field, such as design science in information systems (Hevner et al., 2004), guidelines for human AI interaction (Amershi et al., 2019), and mixed reality user experience frameworks (Alexandrovsky et al., 2021). Each prototype is rated on a five-point scale (1 to 5) that indicates how thoroughly it meets each criterion, with “1” reflecting minimal clarity, relevance, or effectiveness and “5” signifying complete alignment with recommended best practices. By consolidating all prototypes in a single table, this approach highlights both comparative strengths and potential areas for improvement across technical and user-centric dimensions, guiding future enhancements in memory support systems design and development.

The Scoring as Follows

- 1: Unclear, Not Relevant, Not Effective
- 2: Somewhat Clear, Slightly Relevant, Slightly Effective
- 3: Neutral, Average, Moderately Effective
- 4: Mostly Clear, Mostly Relevant, Mostly Effective
- 5: Completely Clear, Highly Relevant, Highly Effective

Below is the descriptive evaluation table.

No.	Prototype	Functionality	Adaptability	Context Awareness	Personalization	Ease of Correction	Proactive Assistance	Multi-Modal Interaction	Immersion Levels	Presence	Attention and Flow
1	WI1, SC1: A-Frame	2	1	1	1	1	1	1	3	3	2
2	WI1, SC1: Adobe Aero	3	1	1	1	2	1	2	3	2	2
3	WI1, SC1: ShapesXR	1	1	1	1	2	1	2	3	3	3
4	WI1, SC1: Niantic Lightship	2	3	3	2	2	1	2	3	3	3
5	WI1, SC1: Meta All in one SDK	2	2	3	2	2	1	3	3	3	3
6	WI2, SC2: Memory Map	2	2	2	2	3	1	1	1	1	2
7	WI2, SC2: Memory Map V2	3	3	2	3	3	1	1	1	1	2
8	WI2, SC2: Memory Map with AI	4	3	3	3	3	2	2	1	1	2
9	WI2, SC2: Frame Maps	4	3	3	3	3	2	2	1	1	2
10	WI3, SC3: Webcam LLaVA	2	3	3	3	3	2	2	1	1	2
11	WI3, SC3: Webcam LLaMa 3.2 Vision	2	2	2	1	2	1	2	1	1	1
12	WI3, SC3: Webcam Florence 2 Large Caption	2	2	2	1	2	1	2	1	1	1
13	WI3, SC3: Frame Vision	4	4	3	3	3	2	2	2	2	2
14	WI4, SC4: AI Voice Assistant (GPT 3.5 turbo)	2	3	2	3	3	2	2	1	1	2
15	WI5, SC5: Text to 3D	2	3	1	3	2	1	2	2	2	2
16	Final Prototype: Mind Palace XR	5	3	4	4	3	3	4	5	4	4

Table 10: Descriptive evaluation of all prototypes

Below is a descriptive evaluation table comparing the case study prototypes to the final prototype.

No.	Prototype	Functionality	Adaptability	Context Awareness	Personalization	Ease of Correction	Proactive Assistance	Multi-Modal Interaction	Immersion Levels	Presence	Attention and Flow
1	Memoro	4	4	4	3	3	3	3	3	3	4
2	Exomem	4	4	4	3	4	4	4	4	4	4
3	NeverMind	4	3	4	3	3	3	3	4	4	4
4	Encode-Store-Retrieve	4	4	4	3	3	3	3	3	3	3
5	Mind Palace XR	3	3	3	2	2	3	3	4	4	2

Table 11: Descriptive evaluation of final prototype with case studies

Definitions of Criteria

- Functionality: Breadth and depth of features, including real-time data. (Hevner et al., 2004)
- Adaptability: Scalability and adaptability across different contexts and technological advancements. (Hevner et al., 2004)
- Context Awareness: Display information relevant to the user’s current task and interaction environment. (Amershi et al., 2019)
- Personalization: Personalize the user’s experience by learning from their actions over time. (Amershi et al., 2019)
- Ease of Correction: Make it easy to edit, refine, or recover when the AI system is wrong. (Amershi et al., 2019)
- Proactive Assistance: System anticipates user needs and offers help before requested. (Amershi et al., 2019)
- Multi-Modal Interaction: Enabling interaction through multiple modalities (e.g., voice, gestures). (Amershi et al., 2019)

- Immersion Levels: The degree of immersion in the virtual environment. (Alexandrovsky et al., 2021)
- Presence: The sense of being present in the virtual environment. (Alexandrovsky et al., 2021)
- Attention and Flow: The ability to focus and maintain attention in the virtual environment. (Alexandrovsky et al., 2021)

In conclusion, the descriptive evaluation table highlights strengths and weaknesses across key design principles. By applying a rigorous, literature-based approach, the analysis not only identifies high performing prototypes but also pinpoints opportunities for improvement. This structured assessment guides future research and development in interactive system design.

7.3.Subjective Evaluation

This section presents a subjective evaluation of how the prototypes progressed from early 360° VR explorations and simple AR overlays to precise location anchoring (Niantic Lightship VPS) and collaborative Mixed Reality (ShapesXR). Each iteration is examined through its intent, impact, and key takeaways. Initially, the focus was on immersion and basic AR, but subsequent versions incorporated AI-driven automated captioning (Webcam-LLaVA, Webcam-Florence), voice-assistance (AI Voice Assistant), and user-driven spatial memory features (Memory Map V2). Wearable smart glasses (FrameVision, FrameMaps) showcased seamless hands-free logging, culminating in the Mind Palace XR prototype, which merged multiple AI capabilities to convert real-world scenes into interactive 3D memory cues. As summarized in Table 12 to 16 below, each prototype's evolving design and advancements highlight the potential for immersive, spatial memory augmentation in future XR innovations.

Below is the subjective evaluation table.

Prototype	WI	SC	Intent	Impact	Key Takeaway
Prototype 1: A-Frame	1	1	Test a 360° VR scene for spatial recall	Immersive environment boosts memorability	Immersion supports recall and opens paths for real-world integration
Prototype 2: Adobe Aero	1	1	Place 3D objects in real-world AR	Location-based overlays reinforce memory cues	Blending virtual objects with real spaces enhances retention and engagement

Table 12: Prototypes Intent, impacts, and key takeaways 1

Prototype	WI	SC	Intent	Impact	Key Takeaway
Prototype 3: ShapesXR	1	1	Explore deeper MR interaction	Spatial Manipulation fosters stronger memory cues	MR is promising; demonstrating promise for AI extensions.
Prototype 4: Niantic Lightship	1	1	Achieve accurate, persistent AR anchors	Persistent references help link memories to physical places	Stable anchor points provide a strong foundation for future AI integration
Prototype 5: Meta all-in-one SDK	1	1	Assess effect of a single static 3D cue	Visual distinctiveness can spark memory	Simple cues can still improve recall; future enhancements can expand interactivity
Prototype 6: Memory Map	2	2	Manually anchor images and labels on a map	User curation fosters stronger personal ownership	Spatial organization helps recall; AI overlays could streamline tagging
Prototype 7: Memory Map V2	2	2	Enhance UI/UX and manage complex map data	Clear clustering and routes improve navigation	Refined mapping fosters richer memory structure, enabling future AI/AR features

Table 13: Prototypes Intent, impacts, and key takeaways 2

Prototype	WI	SC	Intent	Impact	Key Takeaway
Prototype 8: Memory map with AI	2	2	Automate image captioning on pinned locations	Faster labelling and richer context via AI	AI-driven captions enhance the user's spatial timeline, supporting more intuitive recall
Prototype 9: Framemaps	2	2	Map-labeled, AI-captioned photos in real time	Real-time geotagging and visual context expand memory mapping	Wearable AI capture integrated with maps shows promise for live memory anchoring
Prototype 10: Webcam-LLaVA	3	3	Provide live scene descriptions via webcam	Real-time AI annotation enriches user's immediate context	On-the-fly captions are useful, with potential for AR pairing
Prototype 11: Webcam LLaMa 3.2 Vision	3	3	Test an alternative model for scene description	Evaluates different AI for improved image-to-text capabilities	Model variety refines the system's flexibility and accuracy

Table 14: Prototypes Intent, impacts, and key takeaways 3

Prototype	WI	SC	Intent	Impact	Key Takeaway
Prototype 12: Webcam-Florence 2	3	3	Explore large-caption model usage	Offers another approach to AI-generated scene interpretations	Continuous experimentation helps find the best solution for real-time annotation
Prototype 13: Framevision	3	3	Wearable capture + AI descriptions	Hands-free capture and annotations improve on-the-go logging	Smart glasses streamline documentation, and more precise geo-capability can enhance usage
Prototype 14: AI Voice Assistant	4	4	Offer hands-free, conversational support	Voice-based interactions feel natural and engaging	Conversational AI encourages recall; combining with visual/spatial cues could amplify it

Table 15: Prototypes Intent, impacts, and key takeaways 4

Prototype	WI	SC	Intent	Impact	Key Takeaway
Prototype 15: Text to 3d	5	5	Convert text prompts into 3D objects	Quick generation of custom 3D cues reduces modelling barriers	Rapid 3D creation supports personalized memory cues; faster processing would boost usage
Prototype 16: Mind Palace XR	1,3,5	1,3,5	Real-time memory palace through AI scene analysis & 3D conversion	Multi-AI synergy offers immersive, spatially anchored memory reinforcement	Unifying MR immersion, AI vision, and 3D generation has strong potential for future XR apps

Table 16: Prototypes Intent, impacts, and key takeaways 5

Each prototype reflects a deeper level of immersion, stronger AI integration, and greater support for user memory retention. This iterative process underscores the promising future of intelligent and immersive XR experiences. A holistic synthesis of these findings appears in the upcoming section, paving the way for future development and exploration.

7.4. Evaluation Synthesis

In reviewing both the descriptive and subjective evaluations, several key themes emerge. From a descriptive standpoint, prototypes that integrated AI driven features such as automated captioning, voice assistance, and real time scene analysis consistently achieved higher marks on criteria like Personalization, Context Awareness, and Ease of Correction. In contrast, early or purely AR focused prototypes offered immersive experiences but tended to score lower in proactivity and personalization. Nonetheless, each design addressed core user needs in memory support to varying degrees, with “Mind Palace XR” standing out for its multi-AI synergy and comprehensive integration of immersive elements. These findings align with established design science and human AI interaction frameworks, confirming that robust functionality combined with adaptability supports richer engagement and recall.

The subjective evaluations validated these quantitative insights, emphasizing the importance of iterative refinement. Early prototypes emphasized immersion and basic AR overlays, steadily evolving to include features like precise location anchoring, wearable smart glasses integration, and AI based scene interpretation. The hands-free logging and conversational interfaces promote more natural interactions, while real time AI annotations enhance context awareness. Overall, the convergence of AR immersion with AI driven personalization and proactive assistance points to a promising future for intelligent, human-centric XR applications aimed at enhancing memory and recall.

7.5. Public Exhibition

The final prototype is exhibited at the Digital Futures Graduate Thesis Exhibition 2025 (DFX), hosted at OCAD University's Waterfront Campus. This exhibition features thesis projects by graduate students from the Master of Design (MDes), Master of Fine Arts (MFA), and Master of Arts (MA) programs.

The key feature of the exhibition is the guided Mind Palace XR demo application, accessible to visitors through a Meta Quest 3 headset. In this guided experience, users learn about the method of loci and its evolution through the integration of artificial intelligence and augmented reality technologies. Specific locations within the designated exhibition space, such as an imagined coffee shop, florist or gym, serve as physical anchors that enable participants to actively engage with the memory palace technique in an immersive and interactive way. The App generates vivid, three-dimensional memory objects linked directly to these designated physical spaces.

A simplified illustration of the exhibition setup is provided below.

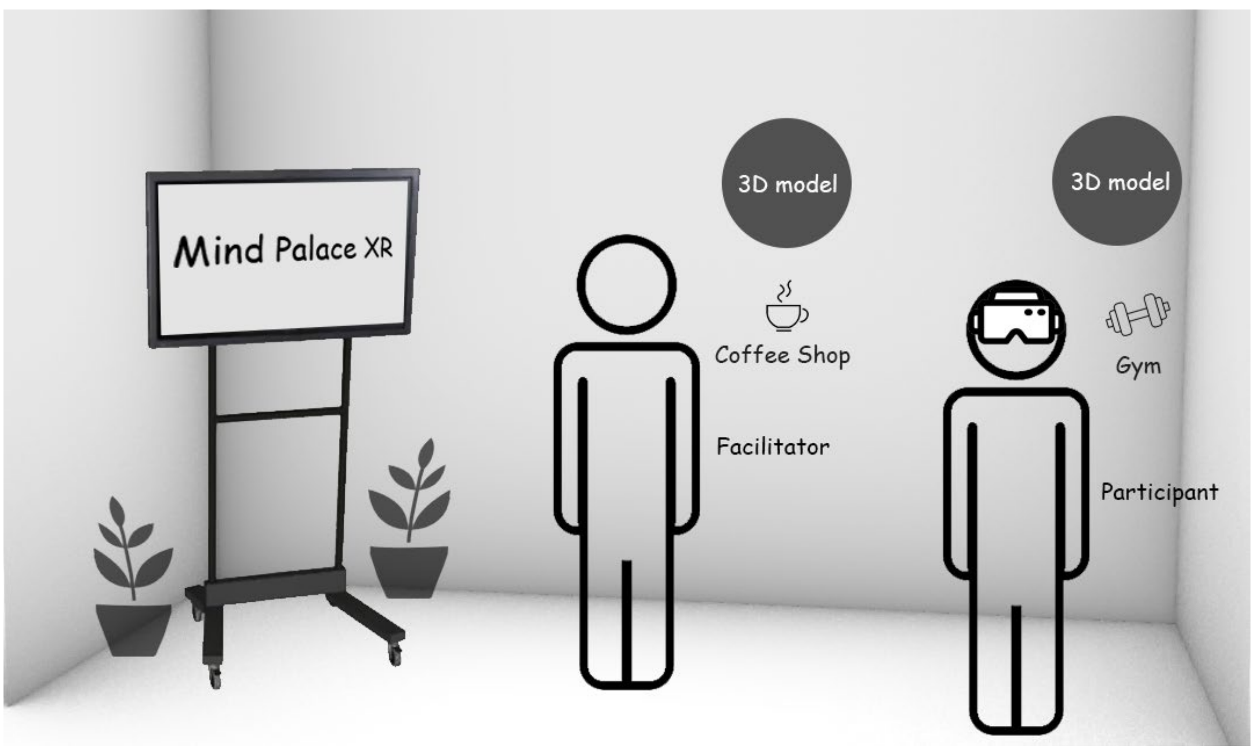

Figure 57: Public exhibition setup

Figure 58: App demo at OCAD U Waterfront public exhibition

7.5.1. Public Exhibition Generations

Below are select examples from the 118 generations created by exhibition visitors, shown as 2D images produced via the FalAI API service. These images represent the halfway point in the

Mind Palace XR pipeline. The code and system prompt were modified to accommodate the small exhibition space by including fun, interactive 3D models for visitors.

Figure 59: Sample 2D outputs from visitor-generated prompts 1

Figure 60: Sample 2D outputs from visitor-generated prompts 2

7.5.2. Public Exhibition Takeaways

The Exhibition of 6 Days gave the opportunity to observe various interactions and gather reflections on the final prototype - Mindpalace XR app. Many found the approach presented to be interesting, holding strong potential that could readily extend to a variety of other uses. The novelty of the experience seemed to stick with people, prompting numerous ideas about how it might be applied across different contexts and industries. The way the app smoothly integrates different AI models to generate results in moments was frequently noted as impressive and efficient. Interacting with the app was often described as fun and enjoyable. The generated shapes received considerable attention, characterized as unusual, imaginative, and visually engaging; some appeared as intriguing combinations of forms. Vibrant colours contributed to their appeal, making the 3D models quite memorable, with some standing out as peculiar. While some simpler 2D visuals were appreciated for a certain nostalgic quality, a few observations pointed out that the 3D textures could seem overly reflective.

The method of integrating 3D models into a person's natural movement within an augmented reality setting, appearing without requiring a search query, was seen as a smart and user-friendly design. This was noted as a thoughtful solution to the common issue of saving digital items like photos or notes but then forgetting to revisit them. Features like the grabbing function and the floating window for navigation were found to work well, contributing to a smooth and intuitive interaction. The core concept exploring association, how a 3D shape might be linked to a specific event or location, was found fascinating. This holds potential for everyday utility, particularly as wearable technologies like smart glasses become more streamlined. Practical suggestions emerged, such as assisting the elderly in remembering specific people or places, like a familiar bank clerk, or using the floating 3D markers as reminders for regularly purchased items during grocery shopping. For those involved in creative fields, the way different AI types are combined was seen as valuable for reducing cognitive load during the creation process. Thoughts also turned toward future possibilities, including more direct integrations like brain-computer interfaces that could eliminate the need for handheld devices. More immediate points included curiosity about how the system functions in outdoor spaces or around large buildings, specifically regarding the placement of 3D models and, crucially, how associations are formed and maintained. Suggestions for enhancement included incorporating an audio interface for even smoother interaction, exploring local AI to allow offline access in areas with limited connectivity, and considering accessibility features for vision impaired users. There was also interest in whether placed models would persist for recall upon returning to a location. The emphasis on keeping agency with the human user, ensuring people remain in control while balancing tasks suitable for AI, was also noted with appreciation.

8. Conclusion

8.1. Personal Reflection on the Thesis

This thesis journey has been deeply influenced by my professional transitions across industrial design, aerospace, defence, and higher education. My early experiences in algorithmic and generative methods illuminated how technology can optimize design processes and spark entirely new ideas. Yet, it was the repeated observation of “forgotten knowledge” within both industry and academia that heightened my awareness of the importance of memory retention. As a design educator, I witnessed firsthand how students struggled to recall foundational theories and techniques, reaffirming the timeless challenge presented by Ebbinghaus’ forgetting curve. These encounters sharpened my focus on how emerging technologies such as Artificial Intelligence (AI) and Augmented Reality (AR) could work in hand with classical mnemonic strategies to address memory gaps. Reflecting on this thesis, I feel a renewed conviction that the wise blend of human creativity and computational intelligence can not only streamline professional workflows but also broaden the cognitive horizons for learners and practitioners alike.

8.2. Restating the Goals and Objectives

The primary goal of this research was to explore how AI and AR could bolster human memory retention and recall by embedding spatial memory techniques, specifically the Method of Loci, into immersive, real-world experiences.

The key objectives of this research are:

- To analyze the foundations of human memory systems and the Method of Loci, examining its effectiveness in memory retention and identifying gaps in existing technological adaptations.
- To explore advancements in AI driven multimodal technologies, evaluating their potential for developing large scale, AI enhanced Method of Loci experiences.
- To experiment with various AR tools and platforms, assessing their capabilities in creating immersive overlays that enhance the spatial and interactive components of the Method of Loci.

- To investigate the integration of AI and AR technologies, developing dynamic, context aware memory augmentation systems that personalize memory retrieval based on user interactions and real world environments.
- To develop speculative artifacts and conceptual prototypes, illustrating how AI and AR can be utilized to create enhanced memory experiences.
- To evaluate and analyze AI AR prototypes, assessing their performance, features, and effectiveness, identifying what worked and what did not through Research through Design (RtD) methodologies within a Speculative Futures framework.

8.3. Restating Contributions

This thesis contributes to the nascent field of AI-AR memory augmentation by proposing a design-led framework that fuses established mnemonic strategies with cutting-edge computational tools. Key contributions include:

- Literature Synthesis: Compiles and analyzes diverse sources on memory science, speculative design, and AI/AR approaches, grounding the research in interdisciplinary theory.
- Integration Framework: Formulates a systematic way to combine AI-driven experiences, AR overlays, and traditional mnemonic methods.
- Proof-of-Concept Prototypes: Validates the integration strategy by illustrating multiple design pathways and potential user experiences.
- Descriptive Evaluation Approach: Establishes criteria and contexts demonstrating the practical relevance of these methods, guiding future development and application.

These outcomes do not claim to offer fully validated, market-ready solutions but rather spark critical discourse on the interplay between next-generation technologies and human cognition.

8.4. Limitations of the Work

While this research successfully employed a speculative design and Research through Design (RtD) methodology to explore the potential of AI and AR in memory augmentation, this approach inherently carries limitations regarding empirical validation. The findings are primarily exploratory and illustrative, stemming from iterative prototyping and reflective analysis rather than formal user studies or quantitative evaluations.

Specifically, the absence of rigorous usability testing and diverse user feedback means the practical effectiveness, usability, and generalizability of the proposed concepts, including the final Mind Palace XR prototype, remain unquantified. The evaluation presented in Chapter 7 relies significantly on descriptive analysis based on literature criteria and the subjective assessment. This subjective evaluation approach, while valuable within an RtD framework for generating insights through reflection, does not substitute for empirical data derived from controlled user testing. Consequently, while the prototypes demonstrate technical feasibility and conceptual promise, their real-world impact on memory enhancement across different user groups requires further research through more conventional empirical methods.

8.5. Directions for Future Work

Acknowledging the limitations of the current work, particularly the speculative approach and absence of empirical user validation, future research could prioritize bridging this gap while continuing to explore the technological frontier. Building upon the conceptual and technical foundations laid here, several promising avenues for future research emerge:

- Comprehensive Voice Interface: Build a two-way speech layer so users can interact with the system with audio interface while wearing AR glasses. Voice input keeps hands free, enriches the visual layer, and supports use on the move.
- Integrated Conversational AI: Develop real-time, context-aware assistants capable of proactively engaging users with memory reinforcement strategies, further bridging the gap between cognition and technology.
- Memory Support Agents: Implement intelligent agents that act as personalized memory support tools, actively retrieving and presenting relevant information based on user context and history. These agents could leverage user memory profiles to offer tailored prompts and reminders within the AR environment.
- Immersive Virtual Environments: Extend the prototypes into fully immersive VR settings, enabling “room-scale” memory palaces and further testing the boundaries of spatial mnemonics.

- Enhanced Spatial Analysis: Investigate advanced environmental scanning and object recognition to improve the fidelity and precision of 3D model placement and occlusion within real-world scenes.
- User Customization and Personalisation: Enable deeper personalization, from aesthetic style choices of AR overlays to the interactive editing and re-positioning of digital memory cues for the commercial consumption.
- Longitudinal User Studies: Plan multi-month trials with varied participants across ages, cognitive profiles, and cultures. Track memory retention, cognitive load, and daily usability to confirm that benefits last outside the lab and extend to broad populations.
- Deeper personalization through small language models: Utilise and train Small Language Models and Compact Language Models on each user's notes, schedules, preferences and media, backed by retrieval-augmented generation (RAG). The system can then craft mnemonic cues, which are custom 3-D objects, styles, stories rooted in personal experience rather than generic content. (Microsoft Phi[57], Google Gemma[58], Meta Llama[59]) (Nguyen et al., 2024).
- Ethical and Privacy Considerations: As AI and AR mature, further work on data security, ethical usage, and user-centric data governance will be crucial to building public trust and ensuring responsible deployment.

8.6. Final Thoughts

In envisioning a future where memory is not just a cognitive function but a dynamic, immersive experience, it becomes possible to see the boundless possibilities AI and AR might unlock. The concepts explored here suggest a world where digital cues seamlessly blend with physical surroundings, allowing once fleeting ideas to become firmly anchored in the tangible spaces individuals inhabit. This transformation could significantly reduce cognitive load, foster better memory, and even reshape how society conceptualizes remembrance.

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[57] Microsoft Phi: Microsoft's small language models (SLMs). Available at: https://azure.microsoft.com/en-us/products/phi/?msockid=100a0b9c9b8165ed02ca1f7f9a126460
[58] Google Gemma: Google's lightweight open AI models. Available at: https://ai.google.dev/gemma
[59] Meta Llama: Meta's foundational open LLMs. Available at: https://www.llama.com/

Ultimately, the aim of this work goes beyond simply prototyping new tools or apps; it involves reimagining the relationship between human memory and digital augmentation. Continuing to push the frontiers of AI-driven and AR-based spatial experiences holds the promise of creating more accessible, equitable, and inspiring tools that help individuals and communities learn, remember, and thrive. If this research fuels renewed dialogue or motivates further exploration in that direction, then it will have fulfilled its broader purpose.

9. References

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10. Appendices

Appendix A: Declaration of AI Tool Usage

Throughout the development of this project, various AI technologies were utilized to facilitate the creation of memory support tools and prototype development along with using the API services for the primary functions of the prototype. Specific applications of these technologies are detailed below:

1. Code Understanding, Modification, and Documentation:
    a. Cursor AI[60]: Assisted in understanding and modifying code structures.
    b. ChatGPT (OpenAI): Provided insights into code functionalities and assisted in drafting the GitHub README documentation.
    c. Claude AI: Offered code analysis and suggestions for optimization.
    d. Gemini: Contributed to code debugging and refinement processes.
2. API Services:
    a. Gemini API: Scene Understanding, Image to Captions.
    b. FAL AI API: Text to 2D Image.
    c. Stability AI API: 2D Image to 3D Model.
3. Image Generation:
    a. Midjourney 6.1: Utilized for generating images incorporated within the project. The specific prompts used with Midjourney are documented in the appendices.
4. Appendices:
    a. Sample outputs from the LLaMa vision model are included in the appendices to illustrate its application within the project.

I confirm that the use of these AI tools was conducted in accordance with ethical guidelines and that all AI-generated content has been appropriately integrated into the project. I take responsibility for the content presented in this thesis.

[60] Cursor IDE: Development environment. Available at: https://www.cursor.com/

Appendix B: Github Repositories

- **Prototype 6**: https://github.com/calluxpore/Memorymap
- **Prototype 7**: https://github.com/calluxpore/Memory-Map-V2
- **Prototype 9**: https://github.com/calluxpore/FrameMap-Photo-Capture-Description-and-Location-Visualization
- **Prototype 10**: https://github.com/calluxpore/Webcam-LLaVA
- **Prototype 11**: https://github.com/calluxpore/Webcam---LLaMa-3.2-Vision
- **Prototype 12**: https://github.com/calluxpore/Webcam-Florence-2-Large-Caption
- **Prototype 13**: https://github.com/calluxpore/FrameVision-Smart-Image-Capture-Description-with-Location
- **Prototype 14**: https://github.com/calluxpore/VoiceAI
- **Prototype 15**: https://github.com/calluxpore/Text-to-3D-Model-Generator
- **Final Prototype**: https://github.com/calluxpore/DF_Thesis_Prototype_Feb10

Appendix C: Sample Output

Content for Section 6.1.3.2

Image Analysis: A Man Sitting in Front of a Bed
Timestamp: Sun, Dec 8, 2024 – 20:56:09

“The image depicts a man sitting in front of a bed, with his hair disheveled and appearing unkempt. The overall scene suggests that the individual may be experiencing some form of distress or discomfort”

1. Physical Dimension

The man's hair is dark brown and slightly messy, with strands sticking out in different directions. His facial features are not clearly defined, but he has a slight scruff on his chin. He is wearing a black shirt, which may indicate that he is preparing for bed or has just woken up.

2. Psychological Dimension

The man's expression appears to convey mild concern or worry, as evidenced by his furrowed brow and slightly downturned mouth. His eyes seem to be gazing off into the distance, suggesting that he is preoccupied with something. The overall atmosphere of the image suggests a sense of unease or discomfort, possibly linked to his mental state.

3. Team Dimension

There is no visible team or group present in the image; the man appears to be alone. However, it can be inferred that he may have interacted with others prior to the image being taken, given the presence of a bed and pillow in the background. The absence of any clear communication patterns or authority figures suggests that he may be working independently or without direct supervision.

4. Organizational Dimension

There is no visible organizational structure or hierarchy in the image, as it appears to be a personal space. However, the presence of a bed and pillow suggests that he has access to basic amenities, which may imply some level of responsibility or accountability. The overall atmosphere of the image suggests informality or a lack of structure, indicating that his work environment may be relatively relaxed.

5. Political Dimension

No explicit signs of policy agendas, budget allocations, laws, or regulations are reflected in the image. The lack of a clear organizational structure or hierarchy implies that the man may have a degree of autonomy in his decisions. The overall tone of the image suggests a sense of independence and self-sufficiency, hinting at a relatively permissive environment.

6. Critical Insights

The image suggests that the man may be experiencing some form of distress or discomfort, possibly related to his mental state or personal circumstances.

Appendix D: Prompts of AI Generated Images

- Section 6.1.1 Image generated in Midjourney 6.1

Aisha slips on her lightweight MR headset, immediately seeing a glowing café symbol that sparks recognition. Instead of scrolling through messages, she follows luminous orbs shaped like coffee beans floating along the sidewalk, guiding her effortlessly. Approaching the entrance, a translucent 3D model of two coffee cups appears, vividly recalling their last visit. Nearby, a floating photo of her friend's smiling face triggers a replay of their laughter, mingling with the sensory cue of fresh espresso aroma. Passersby glance curiously at her joyful expression, unaware she's immersed in these rich visual memory cues. Stepping inside, a final image from their past meeting gently fades, anchoring her back into reality. In this new age, memories are vividly woven into daily life through symbolic visuals and immersive cues.

- Section 6.1.2 Image generated in Midjourney 6.1

While strolling through her bustling neighbourhood, Mari uses an app that turns each street corner into part of her personalized memory palace. At the bakery, a small holographic bookshelf hovers, reminding her of the cookbook she borrowed from a neighbour. Near the florist, virtual petals swirl around her, prompting her to recall the time she bought flowers for her sister’s graduation. The app ensures these cues feel natural, placed in exact spots where those memories first took shape. Neighbours start swapping their own memory markers, creating a shared map of personal highlights that sparks conversation among passersby. Families introduce their children to stories rooted in these everyday locations, embedding bits of their lives in the very pavement they traverse. Over time, a simple trip to pick up groceries transforms into a gentle journey through collective recollection.

- Section 6.1.3 Image generated in Midjourney 6.1

A futuristic urban street bathed in soft morning light, where a young man named Jake walks with smart glasses featuring AI-assisted vision. Through his perspective, subtle augmented reality overlays flicker--gentle reminders tied to his past experiences. A glowing note hovers near a lamp post, reminding him of an errand for his grandmother, while a bookstore ahead is softly highlighted with a nostalgic memory of an old friend. The cityscape blends realism and digital abstraction, with transparent UI elements seamlessly integrated into the environment. A balance of sleek technological aesthetics and warm, human emotion is captured in the scene, hinting at the duality of convenience and privacy concerns. The atmosphere feels reflective yet slightly futuristic, a near-future world where digital memory aids shape daily life. Cinematic lighting, cyberpunk-meets-slice-of-life style, hyper-detailed.

- Section 6.1.4 Image generated in Midjourney 6.1

A modern, softly lit apartment where Tanya, a young woman with a thoughtful expression, prepares her morning coffee. Floating air bubbles surround her, each containing subtle words or symbols representing the voice of her AI assistant--an invisible yet ever-present companion. The scene shifts--a quiet train commute, where the same conversational bubbles gently emerge around her, suggesting nostalgic music from a past concert. Later, at work, more bubbles appear as she brainstorms, recalling an old problem-solving technique. The bubbles glow softly, fading in and out as if carrying whispers of guidance, making the AI's presence feel natural yet unobtrusive. The atmosphere is serene yet futuristic, blending everyday life with an ambient, digital touch. Hyper-detailed, cinematic framing, cyberpunk-meets-modern realism, soft luminescent accents.

- Section 6.1.5 Image generated in Midjourney 6.1

A quiet evening in a tranquil park, where Rosa sits on a wooden bench, lost in thought. Soft ambient streetlights cast a warm glow, blending with the cool blue hues of twilight. Before her, delicate floating air bubbles emerge, each holding glimpses of her memory--a childhood moment of her father teaching her to tie shoelaces. At the foot of the bench, a gentle, semi-transparent 3D hologram materializes, vividly illustrating the steps as if time itself is being replayed. She reaches out, rotating and adjusting the scene, savouring long-forgotten details. In the background, others interact with their own holographic memories--an artist shaping a concept from the air, a teacher crafting a lesson from pure imagination. A surreal yet intimate moment where nostalgia and futuristic technology blend seamlessly. Hyper-detailed, cinematic lighting, soft luminescent accents, dreamlike realism.

- Section 6.1.6.1 Image generated in Midjourney 6.1

a person wearing VR headset walking in the middle of street in day light. in anime style.