# Walkable Graph: An Immersive Augmented Reality Interface for Performing the Memory Palace Method

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## Abstract

The objective of our research is to investigate the impact of explorable Augmented Reality (AR) environments on the effectiveness of memory enhancement techniques based on the memory palace method. The memory palace is an ancient technique which uses spatial memory for efficiently recalling information, since the association between learning content and spatial information enables a more efficient learning process. In our research, we use this method not in imaginary environments, as usual, rather in real physical environments enhanced with virtual content. The user walks in an obstacle-free space and by means of an AR interface s/he visualizes virtual graphs, which are overlaid on the floor of the room. An experiment is proposed: a group of test persons applies the memory palace method walking on virtual graphs with our AR interface for associating spatial information and learning content, whereas a control group applies this method using a traditional printed medium.

**Keywords**

Augmented Reality, Memory Palace, Method of Loci, Content Generation.

## Introduction

The memory palace, also known as “method of loci”, is a memory enhancement method which combines the use of visualization techniques with spatial memory to quickly and efficiently recall information (Bower, 1970). This method has a long history and it was already used by ancient Roman and Greek orators for remembering long texts without the aid of notes (Murphy, 2003). The main idea is to create a mental association between physical entities (in particular physical places and locations) and items that the user wants to remember. Memorizing the architectural layout of a building, or the arrangement of shops on a street, or any geographical entity, the user can imaginarily walk through the *loci* (plural of the Latin word locus, which means *place*), by means of a mental visualization and easily retrieve information which s/he previously associated with the memorized spatial entities (Paivio, 1971). The efficacy of this method has been largely demonstrated (O'Keefe et al., 1978; Ross et al., 1968; Crovitz, 1971; Lea, 1975) and it has been demonstrated that it requires less effort for memorizing long lists of items (Hu et al., 2012; Susukita, 1933).

The underlying principle of this method is that the mental visualization of an imaginary environment triggers the spatial memory of the user and consequently the associated information. The effective component of this technique is not the visualization of the imaginary environment itself, rather the involvement of the user’s spatial memory and imaginary motion through the *loci*. The spatial memory of the user plays an important role in establishing and recalling reciprocal associations between spatial context and learning content (Chun et al., 1998; Sharps et al., 1986). By means of the imaginary motion and exploration, the user makes a direct experience, although only imaginary. The traditional use of the memory palace method has three phases: (a) the imagination and mental visualization of different *loci*, (b) the figuration in the mind of the user of the spatial navigation through these *loci* and, as a final step, (c) the retrieval of previously associated information. Several approaches for using this technique integrate Virtual Reality (VR) tools (such as VR headsets or monitor applications) for supporting the visualization of the memory palace. If on one hand, the use of VR tools supports the visualization and the mental representation of the *loci*, on the other hand, the second phase of this method, that is the mental exploration of these *loci*, always happens by means of the user's stationary mental exploration. According to Huttner et al., 2017 and Maguire et al., 2002: "the effectiveness and longevity of this method suggest a natural tendency to use spatial context to memorize and recall information". Therefore, spatial memory and spatial context play a fundamental role. The assumption of our experiment is that the physical movement of the user, who literally walks within a memory palace, can strongly help the user and support her/his spatial memory. If the motion through the *loci* is not imaginary rather real, further perceptual elements are involved and the associated information could be easily recalled. The involvement of psychomotor components by means of the real ambulation of the user represents a new paradigm for the application of this ancient technique.

For enabling the physical exploration of a memory palace, we developed a system based on an AR interface. The user wearing a head-mounted display (HMD) walks in an obstacle-free space and visualizes virtual content, which is overlaid on the floor of the room. Since we want to investigate a realistic use case which can have concrete repercussions on the adoption and use of AR applications, we developed an AR interface for facing a real problem of the publishing industry and we cooperated with an important German publisher. Together we developed the concept of "walkable graph", which is a diagram anchored to the floor and explorable by the user physically walking on its virtual nodes and edges, for exploring the content of published academic publications. The automated content creation of the explorable virtual content plays a fundamental role in the generation of the memory palace and for its application in a realistic and relevant domain. We designed a system based on natural language processing and automated knowledge extraction techniques for identifying textual information which enables the automated generation of the walkable graph. The virtual content that the user explores is triggered by the nodes of the parametric graph and it makes possible to associate and visualize data about publications provided by the publisher.

## Related Work & Theoretical Foundations

In recent years, some attempts have been made to integrate VR tools to benefit from the method of *loci*. Kivisik, 2016, conducted an experiment using an immersive VR headset to study the characteristics of environments that affect the effectiveness of the memory palace method. The experimental results indicated that meaningful locations had a positive effect on the memory of the test persons, whereas an effect of environmental segregation on the memorization of the participants could not be determined. Vindenes et al., 2018, conducted several experiments to investigate which type of people benefit more from the memory palace method. Their results suggest that participants with higher spatial ability obtain more benefit from using this method. Huttner & Robra-Bissantz, 2017, investigated the impact of an increased level of immersion on the effectiveness of the memory palace method conducting an experiment with two groups, which were instructed to use the method to memorize and recall five lists of words. For exploring the memory palace in VR, the first group used a virtual environment presented on a laptop, whereas the second group used an immersive HMD. The HMD group outperformed the laptop group in terms of accuracy and actual use of the instructed method. Huttner & Robbert, 2018, published a study in which they discuss how mental factors such as creativity and spatial abilities affect the design of a virtual memory palace. They argue that if the predesigned memory palace does not fit the mental factors of the user, no optimal design in the user's mind can be achieved, thus reducing the effectiveness of the virtual memory palace method.

Recent research studies investigate the use of AR for performing the memory palace method. Fujimoto et al., 2012, developed a system for evaluating the relation between the position of information visualized using AR and user's memorization. Ibrahim et al., 2017, used an AR system for dynamic labeling of real objects disposed on a table. The user sat at the table uses the memory palace method for associating objects and information. Yamada et al., 2017, developed an analogous AR system for labeling objects to improve the memorization during foreign language learning processes. All experiences which use AR interfaces for performing the memory palace method apply this technique statically, privileging the visual component instead of the motoric component. They do not involve aspects such as walking or physically exploring real environments for performing the memory palace method. The analysis of the related work highlights the need to focus on the involvement of psychomotor aspects for considering the spatial cognition of the user during the memorization. In this sense, due to the integration of walkable graphs and AR environments which are physically explored by the user, the approach that we propose goes beyond the state of the art.

## Methodology & Research Approach

Our research follows a design science research methodology. The focus of our work is the design and development of an artifact with the intention of improving its functionalities by means of experimental iterations and target-oriented user studies. According to Hevner's design science research methodology (Hevner et al., 2004), our research follows seven guidelines (G) to be rigorous and relevant. The AR interface for the exploration of walkable graphs, which are automatically generated and enable to perform the memory palace method, represents the innovative and purposeful artifact (G1). The introduction section specifies the relevance of the research problems and the problem domain (G2). The aspects concerning the evaluation of the artifact and the proposed experiment (G3) are considered in the section "Experimental Design & Evaluation". In the section "Prototypical Implementation" we describe the first prototype of the presented artifact for showing the feasibility of the system and its innovative strength (G4). The section "Methodology & Research Approach" shows the respect of a rigorous methodological procedure, which reflects the coherence and the consistence of the artifact (G5). Considering the design science as a search process (G6), in the section "Related Work & Theoretical Foundations" we show that the presented approach considers the relevance of previous related work. The purpose to communicate our research (G7) is expressed publishing this paper for enabling further discussions among the scientific community.

The execution of experiments for evaluating our artifact has a fundamental role in our investigation. By means of the analysis and test of our AR interface, it is possible to deduce the validity and viability of our approach. The following research question has been defined:

**RQ**: How can we apply the memory palace method in a real physical environment for supporting the spatial working memory of the user without involving imaginary environments?

The following hypotheses are investigated for answering the research question:

**H1**: Using AR-based walkable graphs for performing the memory palace method without involving imaginary environments will result in an enhancement of the spatial working memory of the user.

**H2**: Using AR-based walkable graphs for performing the memory palace method will result in a higher retrieval rate of memorized information than performing the memory palace analogically.

We planned different cycles of experiments with an iterative approach for evaluating our artifact. By means of the experiment that we are presenting in this paper, we evaluate and measure the variables that we introduced in our hypotheses. The enhancement of the spatial working memory of the user is measured as the accuracy of the ability to properly associate memorized information and *loci*. According to the closeness of the measured value to the known value, the user of the experimental group receives a specific score. A comparison with the score values of the control group returns a measurement of the effectiveness of our AR system (see **H1**). The retrieval rate of memorized information is then compared between the group composed by test persons using our AR interface and the control group composed by test persons performing the memory palace method in a traditional manner, without using the HMD. The accuracy of the ability to recall memorized information defines and measures the retrieval rate (see **H2**).

## Prototypical Implementation

The artifact that we designed for demonstrating our hypotheses is an AR interface for Microsoft HoloLens. In cooperation with an important German publisher, we identified a specific use case for readers of academic publications. A user who reads an academic publication in digital or in printed form has the possibility to reach further virtual content and to explore walkable graphs containing information, which is thematically related with the publication, by means of our AR interface. A practical example is the walkable graph for reference clustering. Academic papers have a list of references, which are essential for the comprehension and the scientific validity of a publication. These references provide different kinds of information and can be clustered according to their topic (e.g. references about the methodology of the paper, about a specific subcategory of related work etc.). The generation of a walkable graph for summarizing the different categories which are detectable in the list of references makes possible to generate a memory palace for their deeper comprehension and memorization. Moreover, it enables to enhance this information with further virtual content such as abstracts, keyword list, mind maps (and much more) about the listed references, which are accessible simply walking on the walkable graph.


**Image 1. Screenshots of our "Walkable Graph" for Microsoft HoloLens**

For enabling the generation of walkable graphs for reference clustering by means of automated processes, we developed two main system components. The first component is the *Knowledge Extraction Platform* and the second component is the *AR Interface Development System*. The *Knowledge Extraction Platform* makes possible the mining of information from a text corpus for extracting data related to the references of several academic papers which are available in our database. This component collects all available information about the papers listed in the references of each article listed in the database. By means of natural language processing and information retrieval techniques, the references of every analyzed academic publication are clustered into thematically related groups. This means that the output of the *Knowledge Extraction Platform* is a vector containing, among other information, reference list and groups of references for all available items of the dataset. The list with the groups of references contains group names and list of thematically related references for each group. This information is automatically generated and updated each time a new publication is listed in the database. The *AR Interface Development System* implements this data and generates the walkable graph, which is a diagram with edges, nodes and an origin. By means of a priori defined parametrization of the final graph, the *AR Interface Development System* collects all relevant information for defining the final structure of the walkable graph. Collected information about the number of groups, their names and the quantity of related items enable the definition of the edges of the graph. Collected information about the typology of the node (group node, reference node, origin etc.), node properties and related virtual content to be shown enable the definition of the nodes of the graph. This data, which is specific for each analyzed academic publication, is used for generating the walkable graph for reference clustering modifying parametrical variables and constraints of an exemplar model of walkable graph that has been previously modeled.

## Experimental Design & Evaluation

For evaluating our research approach, we planned and designed an experiment with an experimental group and a control group. The groups have equal gender distribution and the participants with at least a previous knowledge of the memory palace method are evenly distributed between the groups. The experimental group of at least 20 students tests our system. All participants perform the experiment under the same conditions. Each test person uses our AR interface for exploring a walkable graph for reference clustering related to the same academic publication. By means of the HMD, the test person applies the memory palace method physically walking on the walkable graph. Before and at the end of the experiment, the test persons complete a standard questionnaire based on the Nasa-TLX. The experiment has two steps: during the first step the test person has the possibility to learn how to use the HoloLens and to experience how the device works for five minutes; during the second step the test person tests our AR interface for five minutes without external interferences. The behavior of the participants during the second step is tracked and a graphical representation of the movements within the room is created by means of motion capturing techniques for each test person and compared with the results of the evaluation. At the end of the session, the test persons complete further questionnaires for evaluating the accuracy of their ability to properly associate memorized information and *loci* and the accuracy of their ability to recall memorized information about the references of the explored publication, which is the same for all participants. Their ability to recall the memorized content is tested in three different time spans: after 10 minutes, after 1 day and after 7 days. For comparing the results, the control group of at least 20 students applies for the same amount of time the memory palace method in a traditional manner, without using our AR interface and reading a printed version of the same walkable graph explored by the experimental group.

At the end of the session, the test persons of the control group complete the same questionnaires after performing tests in the analogous three different time spans. The results of the two groups are then compared, analyzed and interpreted for evaluating the effectiveness of our approach.

## Conclusion & Outlook

This research provides a novel approach which uses explorable AR environments for performing an ancient memory enhancement technique. Our objective is to provide a methodologically valid initial basis for encouraging further research on this topic. A specific research question has been defined and two hypotheses are derived for investigating the application of AR technology for learning enhancement and its experimental evaluation. Variables and metrics for evaluating our hypotheses have been specified and considered. An artifact has been designed and a first prototypical implementation has been developed for testing our approach. The design of an experiment is proposed, according to the presented theoretical framework. This experiment is part of an iterative process which we use for improving the performance and the quality of the proposed artifact. Several further experiments are planned for measuring the impact of our approach. Aspects regarding the evaluation of the degree of automation for the automated content generation will be considered and evaluated in further research, together with aspects related to the evaluation of the usability of the user interface. We expect that testing our artifact will result in a clearer picture of the underlying dynamics related to the use of AR interfaces for learning purposes.

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