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Published in:
Proceedings - 2023 IEEE International Symposium on Mixed and Augmented Reality Adjunct, ISMAR-Adjunct 2023

DOI:
10.1109/ismar-adjunct60411.2023.00116

Publication date:
2023

Document Version
Peer reviewed version

Extending the World-in-Miniature Metaphor to Access Situated Information in a Pervasive Augmented Reality Environment

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Figure 1: Screenshot of the WiM prototype running inside the experimental environment.

Abstract

Recently, the concept of Pervasive Augmented Reality (PAR) was introduced. It is defined as a continuous use of Augmented Reality (AR), where the information displayed comes from applications simultaneously opened by the user or from situated and embedded information placed by various sources. This can lead to potential information clutter. Additionally, PAR environments apply physical constraints over users due to the nature of their displayed information, forcing users to walk to get to situated or embedded information in the environment if they want more details. This work explores the use of the World-in-Miniature (WiM) metaphor inside a PAR context and extends this technique to better fit the constraints implied by such a context: 1) search and filter information of use wherever it might be, 2) access potentially distant and/or occluded information without any required physical movement, and 3) keep context of distant and situated information. Our contributions are an extension to the WiM metaphor and the evaluation of a fully working prototype through the User Experience Questionnaire (UEQ) with results coming from 26 participants.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality;

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1 Introduction

Research around Augmented Reality (AR) has seen a consequent development last decade. Head-Mounted Display (HMD) is now a mature technology, with devices such as the Hololens, the Magic Leap and soon the Vision Pro available for sale. Despite limitations that are currently hindering their democratization among the general public, these devices have demonstrated their versatility by finding various applications, such as in the fields of medicine, military operations, and industrial maintenance [7]. However, existing devices are not yet ready for PAR scenarios and there are certain considerations that need to be addressed before reaching that goal. One of them emerges from the continuous use of AR implied by such device. Having a screen constantly on one's head displaying information based on the user's context, contrasts with the current sporadic use involved by our current smartphones and computers. Such usage of AR was first described by Grubert et al. [9] and was named Pervasive Augmented Reality (PAR). It is described as a continuous use of AR where multiple applications are opened simultaneously, displaying their content side by side.

In a previous work [8], we conducted a user study where participants were immersed inside a PAR street-like scenario. Participants were asked to go around and find information inside that highly dense environment. Results demonstrated that participants felt overwhelmed by the amount of information and experienced difficulties in finding the requested information. Besides, they perceived the need to move around to search and obtain virtual information as a step backward. Indeed, current technologies allow anyone with an internet access to get access to any information from anywhere in the world. However, in a scenario such as the one described above, a large part of the meaning conveyed by the information displayed depends on where the information is located. Different local authorities (e.g. government or shopkeepers) may add information in the Virtual Environment (VE) and this information, when situated in its context, will take its full meaning when situated in its context and environment [18]. Therefore, decoupling visualizations from a VE from the world in which they are situated cannot be done without losing part of their semantics.

Based upon these three identified requirements (i.e. 1. search and filter information of use wherever it might be, 2. access potentially distant and/or occluded information without any required physical movement, and 3. lose the minimum amount of information when viewing distant situated information), this paper addresses the following question: *how can we provide access to distant and potentially occluded situated information from any location without losing the semantic aspect of its placement?*. We first review the literature to find potential solutions to the problems elicited above and then, based on the relevance of these solutions, improve a commonly used interaction technique to better match our use case. This work also tests a fully working prototype using the User Experience Questionnaire (UEQ) [13]. We finish with a discussion of the results and a conclusion of our findings.

2 Related Work

In this section, we review the current literature on techniques that can address the research question mentioned in Section 1. Three main families of techniques can be identified: a) view management techniques, b) the egocentric techniques, and c) the exocentric techniques. For the last two, we follow the definition of Poupyrev et al. [25] applied to selection techniques. The egocentric category regroups any interaction centered around the user, where they interact directly from inside the world, while the latter presents techniques allowing the user to interact as if from outside the virtual environment with a God's eye point of view.

2.1 View Management Techniques

In the context of PAR, multiple works have addressed the problem of information clutter. Lindlbauer et al. [14] have explored how, where and when applications should be displayed using an optimization algorithm. Based on the user's context, including their task, the proposed solution will adapt window-like applications by reducing their size, content and placement in the virtual environment with what has been named multi level of details interfaces. Using context-awareness is a common approach to handle view management, as demonstrated by the work of Caggianese et al. [6], Lu et al. [16] or Orlosky et al. [22]. However, reducing information clutter in the virtual environment may help identify near user information, but won't help find results for hidden or distant information. Besides, automatic techniques are based on heuristics or learning models and although they try to determine what the user wants, they are never an exact model of the user's thoughts and reflections. Manual techniques include highlighting the desired content or hiding the not desired one.

2.2 Egocentric Techniques

Another approach involves the use of search and navigation techniques. If we disregard how the user enters their search, they help guide him to the various points of interest. Focus&Context techniques consist in showing in detail an element of interest, while other pieces of information are only presented with reduced detail. This often takes the form of a magic lens [15] or X-ray view [1, 11]. In all cases, this technique modifies how the user perceives the world and are strongly related to the user's view (i.e. depend on where the user looks). In contrast, visual aids guide the user to the element of interest without modifying the world perception but by attaching an indicator to the user's view. They can take the form of 3D models placed in the world [4, 21] or, 2D/3D models fixed to the user view [10, 23]. All techniques have advantages and drawbacks, but in general, the precise location is not indicated until the user has moved to the target.

2.3 Exocentric Techniques

According to Poupyrev et al. [25], there exist two types of exocentric selection techniques. On one hand, the automatic scaling metaphor which consists of the set of techniques that scale the virtual environment, or a subset of it, down. First described by Mine et al. [19], they scale down the entire virtual environment to make objects grabbable and manipulable from within arm's reach. Upon release, the virtual environment takes its initial position and scale. This has multiple advantages: it uses proprioceptive information, provides a direct mapping from hand motion to object motion, while also giving more granularity in the precision of motion. However, this technique restricts its interaction to in-view content, and the user is limited to interact with content that is accessible according to their arm's length as stated by Pierce et al. [24]. On another hand, the World-in-Miniature (WiM) metaphor was first described by Stoakley et al. [27]. The technique presents the user a miniature representation of the world where selection, manipulation, travel and visualization tasks can be performed. Since its first description, multiple papers have explored ways to improve the metaphor. Bell et al. [2] explore collaborative work while also using the WiM as a way to access distant and non-visible information. Nam et al. [20] try to extend the WiM technique to make it possible to compare visualization from multiple worlds. Finally, Bluff et al. [5] explore recursive interactions between the WiM technique and the virtual world. A recurrent problem with the WiM metaphor is that it suffers from a lack of precision when using it in an environment with multiple scales. Bell et al. [3] use the WiM to let users get an overview of their environment while using head movement to augment the WiM size and its content. Trueba et al. [28] address the problem by adding an automatic way of updating the region displayed by the WiM, matching it with logical structures of the world (such as rooms). Wingrave et al. [29] extend the method by letting the user scale and scroll the WiM content in a continuous manner.

2.4 Summary

None of the families of techniques detailed above can meet all the constraints set out in section 1: 1) search and filter information of use wherever it might be, 2) access distant and/or obstructed information without any required physical movement, and 3) keep context of distant and situated information. Indeed, while view management techniques partially solve information clutter, they are not usable for distant information as they force the user to move around the environment to find the desired information. Egocentric techniques present the same issue, even if the user is guided to the information. Moreover, if more than one information corresponds to what the user is searching for, the user will have to go from one place to another. Finally, the automatic scaling technique is limited to in-view content so that obstructed information remains unreachable, and also suffers from information clutter. Only the WiM metaphor allows for distant and obstructed information to be visualized without imposing too much physical constraint over its user. Furthermore, by presenting a small version of the VE, it allows for information to remain situated. However, the metaphor suffers greatly from information clutter. Therefore, we propose to combine the WiM metaphor with a view management technique to allow for information clutter to be attenuated, inside the WiM as inside the VE.

3 Extending the WiM Metaphor

This Section presents the design of a solution combining the WiM metaphor with a view management technique, in the case of a PAR environment. First, the view management technique integration within the WiM is discussed, followed by the design choices made over a working prototype.

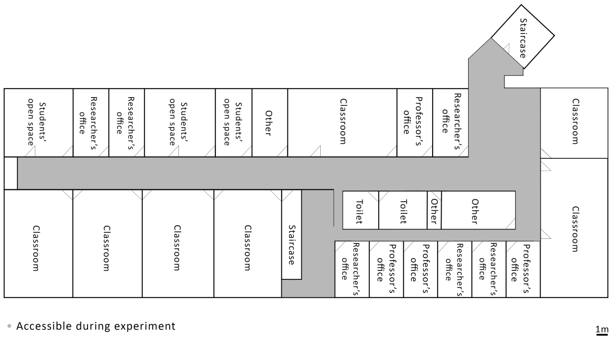
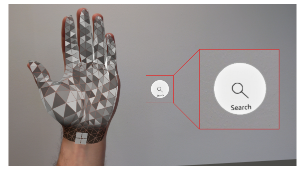
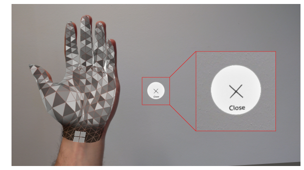


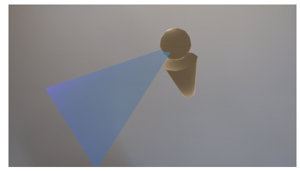
Figure 2: Layout of the environment where the study took place.



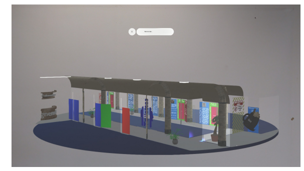
(a) Button to open the WiM.



(b) Button to close the WiM.



(c) User representation used inside WiM. The blue halo represents the user's gaze.



(d) A blue plane delimits the zone of interaction of the technique.

Figure 3: Overview of different functionalities of the WiM prototype.

3.1 View Management Integration

To find content present in the VE, we turn to a text-input based approach. Doing so allows the user to directly specify the desired information through the use of keywords, and filter out unwanted information inside the WiM as well as inside the VE. It is implemented using a virtual keyboard which requires freehand typing. This approach permits a quick reduction of information clutter, and redirects user attention to matching information. Moreover, since matching information appears inside the WiM metaphor, this gives the user an overview of all information around them, even if it is obstructed or out of sight. The text-based input solution is somewhat similar to what is done in AR browsers, such as in the work from Langlotz et al. [12] for instance. Indeed, based upon a search specified by the user, they display results directly inside the VE. However, in our use case, results contain information already inside the environment, and keywords serve as filters instead of search terms. Therefore, we will be referring to this technique as the *filtering mechanism* for the rest of the paper.

3.2 World-in-Miniature Design Choices

The built WiM (illustrated by Figure 1) was designed as follows. We chose to model a corridor on a floor of our building as the environment for our experiment. The logical structure of the corridor (see Figure 2) was mapped, as did Trueba et al. [28], to a 3D representation. We included the floor and the walls from the corridor (grey part from Figure 2), as both serve as visual aids for information placement, indicating the shape of the corridor as well as the location of various visual cues such as doors. However, we excluded the roof as it does not add any additional value. We then chose to represent exactly the VE in the WiM as it is. We made the WiM accessible anywhere, using a button accessible to the user when looking at their palm (see Figure 3a). When pressed, the WiM appears world-fixed in front of the user. It can be closed using the same button (see Figure 3b).

The implemented filtering mechanism UI is visible on Figure 3d on top of the WiM. It was designed as the equivalent of current smartphone internet search bars. Indeed, most users are familiar with this kind of tool and the way it operates. Therefore, for its visual placement, we used an equivalent approach: it is placed above the metaphor since it is used as an input for keywords, and the WiM serves as the visualization method for the results. When entering keywords, it automatically updates the WiM and the VE content to leave in only matching items. Finally, when the WiM has been modified or if any keyword was written, the displayed content and the map placement can be reset through a button available next to the filtering mechanism.

To allow the user to refine the information, we allowed three types of manipulation; rotating the map, zooming in and out, and moving the map. All manipulations required both hands to be realized and were performed by grabbing the map inside the prototype. Once each hand is grabbing, moving the map is allowed by moving both hands in the same direction, rotation can be performed by moving one hand around the other and finally, zooming in and out is done by moving each hand away or closer respectively.

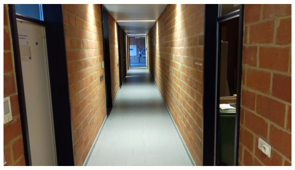
While prototyping, we realized that letting the user move the map along the Y axis inside the WiM restriction zone (see the blue plane in Figure 3d) made the designed filtering mechanism position to be somewhat unpredictable since placed above the map. Therefore, we blocked the Y axis movement manipulation but allowed user to move the map freely over the X and Z axes. Note that we use a left-handed convention for the axes, with the Y pointing to the top and the Z pointing forward.

We first considered blocking all axis for rotation since it helps users transcribe the WiM content to the world as explained by Wingrave et al. [29]. However, after some testing and reflections, we realized that blocking the Y axis implied too many physical constraints to gain access to all information. We therefore unlocked that specific axis. To overcome the potential induced orientation problem, we represented the user in the form of an avatar (see Figure 3c) moving inside the WiM according to their position and orientation inside the environment.

To enable the WiM to be an autonomous tool and be used with no further user movement, we allowed continuous zooming inside the logical structure without restrictions as did Wingrave et al. [29]. Thus, any information inside the VE can be zoomed in and visualized without the user having to walk to it. However, letting the WiM able to be scaled with no limit created information clutter. Therefore, we limited the WiM interaction area to a specific zone (see the blue plane from Figure 3d) and removed elements from the WiM that would be outside that delimited zone. As it did not serve any purpose in our use case, we constrained zooming out when exceeding a default value (set to be 1:67 in our case), so that the map can stay visible even after a faulty handling.

4 STUDY

In this section, we present the results of our study on the usability of the prototype described in Section 3. We start the section by describing our participant sample as well as the environment in which the study took place.



(a) Environment with no added virtual content.

(b) Virtual Environment.

Figure 4: Screenshot of the environment where 4a is the real corridor with no added information while 4b is its equivalent with virtual information. Note that the virtual content in Figure 4b is perceived brighter when visualized through the HMD.

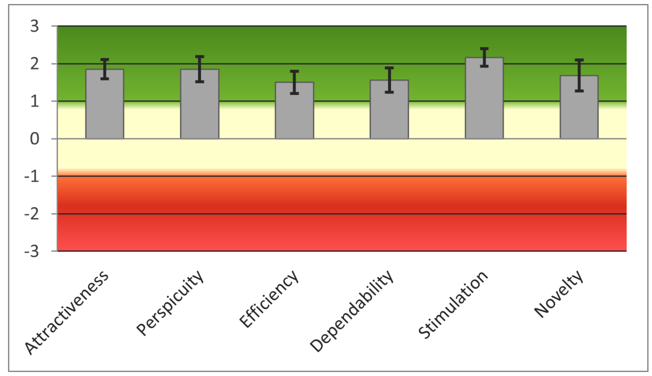


Figure 5: Results from the UEQ.

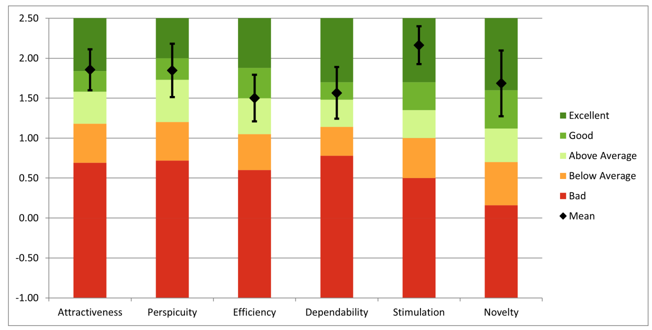


Figure 6: Benchmarks from the UEQ.

4.1 Virtual Environment

The environment where the experiment took place is illustrated in Figure 2. Inside that environment, multiple types of virtual content were added. In front of each door, panels containing information about the room was added, such as agenda, biography, or last research paper for professor's office for instance. Other types of virtual information was added to decorate and populate the environment, such as a virtual broom and bucket, coffee mugs or panels with food prices inside the cafeteria. Figure 4 contains screenshots of the perceived experiment. The VE was adapted from a previous experiment, described in [8].

4.2 Participants

A total of 26 people took part in the experiment, with a distribution of 22 men and 4 women. Except for one participant, none were laboratory colleagues. However, that person does not work on Augmented reality-linked topics and had no previous knowledge of our work. Six had a high school diploma, one had a bachelor's degree, seventeen a master's degree, and two had a PhD. When asked about their familiarity with AR, ten said they had no previous experience, fifteen said they had little experience and one mentioned having some familiarity with the technology. The participants ranged in age from 19 to 38 years old, with an average age of 27.

4.3 Protocol

We received each participant separately inside our office, where two experimenters would systematically be present. We began the experiment with asking the participants to fill in a data protection consent form, and then proceeded by letting them fill in a short survey asking for the information detailed in Section 4.2. We would then describe how the experiment would take place before going to the experiment floor (see Figure 4) where the participant would be given a Hololens 2 headset running the experiment and were asked to adjust it, so that it felt comfortable.

The experimenters then gave the participant time to adjust to the environment. After they felt ready, they would be asked to find information inside the environment. Once the information was found, the participant would then be presented the developed prototype as explained in Section 3.2. They were told that they could open and close the WiM (presented as a tool) by looking at one of their hands and interacting with the virtual button, as can be seen inside Figures 3a and 3b. WiM manipulations as described in Section 3.2 were also presented to them by one of the experimenters and, finally, the filtering mechanism would be presented as a filter working with keywords and having impact on the VE and on the WiM. To let the participant take hold of the tool, they were then asked to use it to find the same information they found earlier without it. Once the participant was comfortable enough and without any other indications from the experimenters, the participant had to use the WiM to find three different pieces of information located in the environment. Experimenters took note on how the WiM was used by the participant. When all questions were answered, experimenters and participant went back to the office. The participant was then asked to fill in the UEQ about the tool usage. Finally, a few open questions were asked to confirm observations taken during the experiment.

4.4 Technical Notes and Limitations

The described prototype from Section 3.2 was implemented through Unity version 2021.3.6f1. It uses the Mixed Reality Toolkit (MRTK) version 2.8 and was designed to be run on the Microsoft Hololens 2. The VE was registered upon the corridor using MRTK World Locking feature. The filtering mechanism uses the native keyboard from the device and, as such, includes the possibility to use the dedicated speech-to-text feature. Also, it uses a Levenshtein distance based algorithm to filter the content from the scene.

4.5 Results

Results are illustrated in Figure 5 and 6. From the initial 26 questionnaires, 3 had to be removed because of inconsistencies, as advised inside the UEQ Handbook [26]. UEQ results show strongly positive user experiences, with a score of 1.855 for the Attractiveness scale, showing that participants liked the overall experience of the WiM prototype. Regarding the hedonic quality (score of 1.92) of the prototype, it shows participants liked the non-goal-oriented aspect of the WiM prototype. Indeed, with a score of 2.163 for the Stimulation and 1.685 for the Novelty, their respective benchmarks are in the "excellent" category. Concerning the pragmatic quality (score of 1.64) and its different components, scores range from 1.5 to 1.85. The Perspicuity aspect reflects how easy it was for them to apprehend the prototype and its interactions. While we told participants how they could interact with the prototype as we did in Section 3.2, they were left with no further instructions. Using the map and the filtering mechanism, understanding their use was apparently easy as confirm the score of 1.848 for Perspicuity and its benchmark qualified as “good”. The Efficiency aspect reflects the difficulty it takes to use the prototype to solve a task. With a score of 1.5, it confirms that the WiM metaphor along the filtering mechanism developed helped participants find information quickly across the developed VE. Finally, for the Dependability aspect, our prototype shows good results too. A score of 1.565 and a benchmark marked as “good” indicates that users felt in control of the tool.

Furthermore, notes taken by the experimenters identified different behaviors among the participants. First, while using the keyboard to enter keywords inside the filtering mechanism, 7 participants tried to use integrated voice input, but only one of them succeeded. 2 others said that it would be a nice feature to have, but did not find the dedicated button. However, almost all participants agreed that the keyboard was not easy to use at first and was time-consuming. Another interesting user behavior observed is the way participants obtained the information. Once they were presented the WiM, all but one user found it natural to filter information in the VE. 19 participants used the zoom feature of the WiM to reach for the information, while 4 identified the place before going there physically. 3 others used both options. Subsequent discussions with the four participants that walked revealed that 2 of them did not understand that the zoom feature allowed them to get the information, but would have probably used it. Four participants would have liked more visual links between the filtering mechanism and the WiM itself. Additionally, 8 participants have tried or would have liked to click on the content in the WiM to enlarge it. Finally, all participants except one saw the interest and use of such a tool.

5 Discussion

The results presented in section 4.5 prove that the WiM as presented is effective and fairly well adopted. However, the excitement of the novelty brought by AR must have played a part in achieving such good results for the hedonic qualities, despite the acclimatization periods given to the participants. Also, it should be noted that some participants expressed difficulties while using the device keyboard. While speech-to-text was available to the participants through a button inside the keyboard, lack of haptic feedback made freehand typing on the keyboard hard for some participants. Exploring other text entry methods for the filtering mechanism using multimodal interaction such as the work from Lystbaek et al. [17] could enhance user experience and improve the Efficiency aspect. Additionally, the short period of use cannot let the participants totally experiment the prototype in a case of PAR where the continuous use of the AR without interruption in the day must play an important role. Material constraints such as weight and battery life mean that we can not assess this point, but future evaluations will have to be carried out when technological developments allow.

As expected, the majority of participants used the zoom to consult information instead of moving to the actual position in the environment. This stayed true unless the participants considered the information close enough to directly walk to it, instead of relying on the zoom feature of the WiM. That is, when it takes longer to zoom than to move. This observation leads us to hypothesize that zooming alone is probably not the most effective technique for consulting WiM information. This hypothesis was supported by the 8 participants who would have liked to have clicked on the element instead. Combining the two techniques should help reach a larger group of users.

Another observation of this study is the user’s preference on the feedback after a search. Despite our explanation that the WiM is a mirror of the environment, some participants did not perceive the change after typing their request. Reinforcing visual feedback by guiding the user’s gaze towards the WiM may help a new user to understand where the response appears. Additionally, we make the choice of hiding non-related elements to the request. However, we remarked that it was not possible to quickly determine whether certain elements had matched or not. The user is forced to scan all the WiM to determine all location where information is still displayed. Presenting results inside the WiM ordered according to a search-based notion of importance would probably improve the effectiveness of this tool.

Finally, our prototype is a working solution for situated information but cannot evaluate embedded information. Embedded information [18] goes a step beyond situated information, as it is closely embedded with its surrounding environment (as much contextually as semantically). The WiM as presented allow the visualization of all virtual information and schematized real-life information such as the floor and wall. Therefore, future works may be interested in whether and, if so, how embedded information should be integrated into WiM. In the same way, for both situated and embedded information, it is important to study the amount of real information that needs to find its way onto the WiM. In all cases, this problem reinforces the need to associate guiding techniques with our solution, such as the ones discussed in Section 2.2.

6 Conclusion

In this work, we explored how different sets of techniques can be combined to meet a PAR environment constraints. By using the WiM metaphor, we can mitigate the situated information visualization problem while also allowing the user to access distant and/or occluded information without any physical constraint and still keeping the meaning associated with the position. Combining it with a view management technique, we are also able to reduce the displayed amount of information, thus reducing the visual clutter the WiM metaphor and the VE suffer from. We built a fully working prototype and its evaluation with 26 participants shows the prototype is appreciated both for its hedonic and pragmatic qualities. The prototype allowed participants to quickly identify the needed information, and permitted them to access it without having to move. User testing allowed us to identify interesting user behaviors. While the majority preferred to strictly use the map as a way to access distant information, some users liked to move directly to the physical position indicated on the WiM.

Acknowledgments

Research for this article was supported by the Region of Wallonia (Belgium) through the Pole MecaTech fund, in projects FLARACC (nb. 8482) and OPTIMIS (nb. 8564). We also thank all the participants from the study for their participation.

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