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Interaction Techniques to Control Information Clutter in a Pervasive Augmented Reality Scenario

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Abstract. The recent concept of Pervasive Augmented Reality (PAR) predicts the use of Augmented Reality (AR) in every aspect of our daily life to help access, produce and present information and services from various different sources around users. However, as far as the authors know, no study explored how design interaction techniques can be implemented in a complex and overwhelming PAR environment where information clutter is generated from multiple sources with very different political, social and economic interests. The contributions of this paper are 1) an evaluation of a PAR street-like environment with multiple producers of information, 2) a proposition of four different strategies, and their related interaction techniques, to help users tackle information clutter around them and 3) guidelines on expected interactions for managing such flow of information, based on participants' feedback.

Keywords: Pervasive Augmented Reality · Interaction techniques · Information clutter.

1 Introduction

The growing complexity of systems in industries, the will to offer a better healthcare, or the need of a better immersion in arts, are examples that lead computer science research to find new solutions. One of them, emerging this last decade due to the improvement in computer hardware, is Augmented Reality (AR). According to Azuma [1], AR can be defined as the integration of virtual data within the real world in real-time and registered in 3D. Such technology can be experienced with a smartphone, or through the use of a Head-Mounted Display (HMD) for instance. It allows immediate access to information in relation with the users' context by placing information directly in the real world. If mobile computing brought the "everywhere, every time" paradigm, AR breaks the frontier between the virtual and the real. Although this is less the case with

⋆ These authors contributed equally to this publication hand-held smartphones, HMDs will allow, with time, the user to forget that he is going through a screen to consult virtual information. The community named this approach immersive AR where the real world and the virtual environment tend to be indistinguishable.

Today, AR is proving its effectiveness in numerous domains, as demonstrated by Dey et al. [3]. By giving the right information at the right time and in the right place, this technology is spreading from laboratories, to economic and governmental actors. Industries are deploying AR systems in training and step-by-step guiding systems for maintenance. Some armies have equipped soldiers and/or their vehicles to augment their speed of reaction and their efficiency in the field. It is also used by surgeons to optimize the success rate of surgeries, allowing them to see organs, blood vessels, penetration of their tools, etc. superimposed on the patient's body. Although still limited to smartphones at the consumer level due to high costs, limitations and social constraints, it is plausible to consider that AR will continue to spread within society the same way personal computers, the internet and smartphones did.

Sci-fi works from the media industry have already tried to illustrate dystopian or utopian futures. One of the most thought-provoking is the "Hyper-Reality" video of Matsuda [10]. It presents our world where AR is overused in every aspect of the user life; publicity, entertainment, tourism, etc. (See Figure 1). Matsuda's work raises many questions. One of them comes from a new possibility offered by such technology; situated information. As stated by Prouzeau et al. [20], situated information is data visualizations which are located close to their physical referent. Considering a world similar to what is depicted by Matsuda, anyone would be allowed to create situated information to be displayed and perceived by other users; professionals, artists, public and private actors. With continuously added information coming from various sources, displayed visualizations might occlude important real world elements and as such, become obtrusive and overwhelming as explained by Lu [13].

In this paper, we focus on how interactions can help users to better appropriate a full Pervasive Augmented Reality (PAR) environment. Following the same approach as Lu et al. [14], we conducted two studies. A pilot study which consisted of semi-structured interviews to assess the feelings of participants in the vision proposed by Matsuda [10]. In response to these results, we elaborate three active interaction strategies and one passive: 1) situated information on-demand with gaze interactions, 2) transparency management for non-readable content depending on the distance to the user, 3) reducing or increasing the number of virtual elements in the user's environment through preferences and 4) situated applications in a virtual smartphone. The experimental study implements and tests these strategies in a real AR environment of a building floor, following the design illustrated in Figure 1. The goals were, on the one hand, to evaluate the impact of the strategies on the cognitive load and feelings of the participants and, on the other hand, evaluate how well the strategies current implementations perform.

Fig. 1: Illustration of an augmented street by Matsuda in his "Hyper Reality" video.

Our contributions are 1) an evaluation of a Pervasive Augmented Reality street-like environment with multiple producers of information, 2) a proposition of four different strategies, and their related interaction techniques, to help users tackle information clutter around them and 3) guidelines on expected interactions for managing such flow of information, based on participants' feedback.

2 Related Work

Grubert et al. [6] define the concept of PAR as opposed to Conventional Augmented Reality (CAR). The latter, representing the majority of work in AR research, is task and context related while also having a sporadic use. CAR applications are accessed one by one according to the user needs. In contrast, a complete PAR experience would be continuous and multipurpose oriented. Conceptually, various applications are opened simultaneously and never closed. In such environments, context-aware solutions must be adopted in complement of sporadic manual interactions to prevent the user from losing time managing all opened applications. To this end, Grubert et al. proposed a taxonomy of context sources that can be used to define passive interaction across PAR applications.

The emergence of PAR inside our society raises ethical, social, legal, political and technical issues. Gugenheimer et al. [7] organized a workshop on ethical, social and political impacts in Mixed Reality (MR) research. Unfortunately, the workshop was canceled due to the pandemic. Regenbrecht et al. [21] opened the discussion on the privacy, safety, belief and rights applied to the PAR. What stands out in particular is a careful modulation of what the user sees, proposing a control for managing the quantity of virtual elements displayed, and defining social and legal norms around the subject.

Beside ethical work done in the context of PAR, other works are more focused on view management techniques. Lu et al. [14] explore how AR applications can be presented and interacted with while being unobtrusive and with minimal cognitive effort. Their solution is called glanceable applications (i.e. applications such as Email, Calendar or Fitness minimized inside the user peripheral vision) with which the user can use gaze to expand their content. Their goal was, on the one hand, to compare applications with their equivalent in traditional devices (e.g. smartphones or computers), and, on the other hand, study user behaviors in this pervasive environment. Their results demonstrate a real interest for the use of pervasive applications. Furthermore, the experiment participants desired more interactions than just information access and also wanted to be able to turn on and off the AR to be relieved from the pressure of the digital world. Lindlbauer et al. [12] explore the view management problem of having multiple applications opened as windows for a continuous use of AR. They submit an optimization based approach of determining where, when and how applications should be displayed using interfaces with multiple levels of detail according to the user context and task. Others have also used context-awareness as a way to determine what and/or how information should be displayed, such as [15], [2], [9], [11], [5], [18]. Another PAR related work was realized by Marques et al. [17]. In it, the authors test research and manipulation tasks in a PAR environment. They help the user in their task with the help of three navigation aids. Results showed good appreciation from the participants and interest in diverse daily life activities.

MacIntyre et al. [16] defined multiple requirements that must be met in order for a PAR ecosystem to exist. These are the following : "multiple sources (or channels of interactive information) must be able to be simultaneously displayed and interacted with, channels must be isolated from each other (for security and stability), channel authors must have the flexibility to design the content and interactivity of their channel, and the application must fluidly integrate with the ever-growing cloud of systems and services that define our digital lives.". To our knowledge, no other work addresses issues arising from multiple contents producers in a PAR environment.

Most works focus on applications designed as we know them today on our smartphones, and do not fully exploit the potential of AR. Except for MacIntyre et al. [16], none of the works above explicitly address the problems that emerge from a world where multiple sources of information coexist. Most view management techniques are solving information clutter using context-aware approaches. In this work, we would like to proceed otherwise, by first trying to establish interaction strategies that can be applied to let the user keep control over a PAR environment.

3 Pilot Study

We conducted semi-structured interviews to better understand potential problems conveyed by the illustration of the street in the "Hyper-Reality" video of

Matsuda [10]. Our hypotheses were that the high quantity of information, animations, and the weak coherence of the environment would make information irrelevant and the world oppressive, thus increasing cognitive load. For the interviews, we asked the participants to imagine themselves as pedestrians in an unknown augmented city (i.e. all streets are augmented like on Figure 1). They were told to be visiting randomly the city or simply wanting to reach a specific place. Participants knew that they wore augmented glasses or contact lens that display virtual information. In order to verify our hypotheses, we had multiple research questions: 1) "How do users feel in this type of environment?", 2) "Is the separation between what is real and what is virtual clear?" and 3) "Is the virtual information understood and relevant?".

3.1 Participants

A total of five men and four women took part in the interviews. They were all volunteers, no remuneration was given. Five participants were between 25 and 30 years old, two were between 35 and 45 years old and two were 60 years old. All participants had a master degree, including four who had a PhD in computer science. However, no participants came from our laboratory team and none of them worked in the field of AR.

3.2 Protocol

The meeting was not audio or video recorded. The members of our team took notes. In the case where two interviewers were present, they were both allowed to ask questions, but one had the lead. The interviewees began by giving their agreements for the interview and the use of their answers. After that, their personal information described in section 3.1 were collected and the context was exposed. Next, the photo in Figure 1 was presented to the participants. They were requested to immerse themselves in the depicted environment. Then, the first question stated above was formulated. The interviewees were free to speak and never interrupted. The interviewers asked questions only for more details on a remark or to redirect the discussion through one of the research questions of the interview. When the participants said everything they had in mind and the interviewers had no more questions, the corresponding video part of the street was shown. At this moment, the question asked was: "Does the video change anything to your feelings?". The same procedure as the one for the photo was applied until the end of the interview. Beginning with a photo was a deliberate choice to help the participants analyze the details of the scene.

3.3 Outcomes

Results show that useful information is lost in the middle of the advertising and could even become useless due to the presence of information clutter. On the other hand, some participants mentioned the similarities of such a street with cities like Singapore or New York, noting that the difference with today's big cities is the possibility offered by AR to modify our perception of reality. According to six participants, the perception of what is real is deteriorated, and three participants feared for their physical safety, again due to information clutter. Other interesting observations not related to information clutter are the following. While some participants described a feeling of sickness, at least all agreed that this kind of environment was tiring. Two participants working in the medical field also noted that the environment as presented could greatly affect the health of the population. Either by "driving people crazy", or due to medical syndromes. To conclude, we want to highlight a remark from one of the participants: "This is about the future of cities, not the countryside.". Which raises the question of "what will be the limit of the intrusive advertising in front of these free spaces?".

4 Experimental Study

In this Section, we study the impact on cognitive load of four strategies aimed to solve the problem of information clutter highlighted in Section 3. To begin with, we use gaze based interaction to provide information on demand. Then, we allow the user to specify their desired level of information according to its nature. Afterwards, we develop the concept of situated applications. Finally, for specific information that cannot be reduced, we automate the management of their transparency according to their physical distance from the user. By applying these four strategies, we study their impact on the cognitive load of the user while evaluating their implementation in order to determine how to improve them, should they be effective.

4.1 Pervasive Environment and Constraints

(a) (b)

Fig. 2: Chosen floor for the experimentation, with 2a and without 2b the virtual content. Note that the virtual elements appear more transparent in the screenshot than they appear to users.

To ensure a controlled environment, we realized the experiment on a building floor. We used its corridor as the main place for the experiment, mapping it to Matsuda's [10] vision of an augmented street. We matched the corridor to the street, the doors to shop windows, etc. Realizing the experiment in such an environment allowed us to keep control over weather condition, passers-by, privacy and social acceptance. It also enabled us to fully exploit the potential of the Hololens 2. Such headsets, being Optical See-through (OST) devices, are vulnerable to light variation, therefore controlling the light exposition of the environment solves the issue. In addition, OST devices have the advantage to reduce the possible phenomenon of motion sickness and are less intrusive than other types of AR headsets. However, it should be noted that the Hololens 2 suffers from a restrained Field of View (FOV), therefore users do not perceive holograms inside their peripheral vision.

In order to augment the floor, we designed five categories of virtual elements: 1) Decorations, 2) social norms, 3) navigation indications, 4) room information and 5) advertising. All these categories were inspired from the work of Matsuda [10] as illustrated in Figure 1. Figure 3 shows the placement of the virtual elements on top of the physical layout of the floor. However, virtual pillars and roof as seen in Figure 2a have not been represented for clarity reasons.

For the decoration category, we added pillars and a false roof to break the square red brick look of the corridor. While the virtual roof is higher than the real one, it is still visible and hides the physical roof. In addition to these architectural modifications, we added plants at multiple locations and flying paper planes in the corridor. Finally, we added a chirping birds sound in the background. For social norms, we consider any information considered to be cultural behavioral guidelines and expectations. In this experiment, this is expressed with animated arrows on the ground which indicate on which side to walk depending on the direction you want to go. These are not to be confused with navigation information. Those are either wayfinding signs indicating classroom names, or other visual elements such as the usual toilet sign placed on the dedicated doors or a bucket and a broom indicating the storage facility. We also placed a panel on the entry of the cafeteria to indicate that the access is for staff member only. Two other panels denying access were placed to prevent the user to enter a room always opened and to access the end of the corridor due to a lack of luminosity that makes the headset behave unexpectedly.

For room indications, we defined content depending on the use of the room. For professors' offices, their biography, agenda, last published paper or research domains were added as separate panels. We also added audio content in which the professors talk of their research area to attract passers-by. For classrooms, we added panels with agenda and classroom background noise to give the impression that the rooms were occupied. On the student open spaces, we placed panels with information on the usage of the room, rules of use and, if the room was named after a person, the biography of the corresponding personality.

For advertising, we added four bulletin boards (see Figure 4f) with advertisements coming from students, faculty or university activities. Each panel is

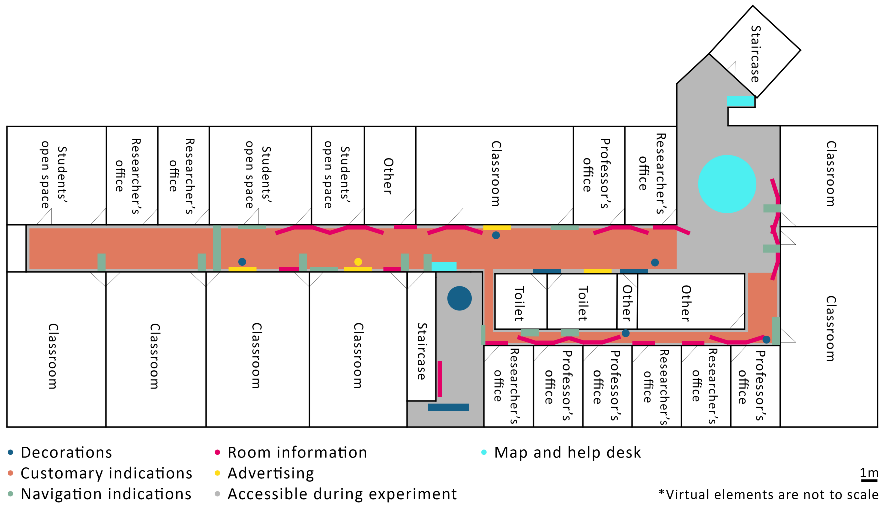

Fig. 3: Layout of the chosen floor.

a square that takes the wall height. It rotates slightly towards the user to be more readable. The panels' content updates every ten seconds, and seven ads in average are presented simultaneously. We also added a teddy bear on one end of the corridor, moving up and down. When looked at for more than 0.8 second, an advertisement appears progressively towards the participant. Finally, in addition to these elements, we added two maps on opposite sides of the floor and a help desk at the floor entry near where the experiment would begin. The help desk holds a penguin in its center who asks the participant if they need any help when they get close to it.

4.2 Four Strategies to Control an Augmented Environment

Based on the results of the Pilot study presented in Section 3, we designed four strategies to help users keep control over their environment. Grubert et al. [6] argue that PAR environments need context-aware automation to reduce manual user interactions. Although we agree with them, context-aware approaches must support user interactions and not replace them. Therefore, users can keep control over the system. For this reason, we propose three strategies that are said to be active, meaning they make use of interactivity and solicit user actions, and one passive. These strategies are foundations on which context-aware automation could be applied. The first strategy uses the user gaze to let them situate and navigate regrouped information. The second strategy lets them specify their preference to filter the amount of information. The third one gives them access to situated applications that give dynamic content based on the context. Finally, the fourth strategy applies transparency to content that is considered too remote to be understood.

In an attempt to make the techniques accessible to the general user, we developed a User Interface (UI) that simulates a smartphone (see Figure 4d). That virtual smartphone lets the user have access to the second and third strategies. While the latter resembles an actual smartphone app, the first has a direct influence over the surrounding world. Therefore, the virtual smartphone is an intrinsic part of the environment.

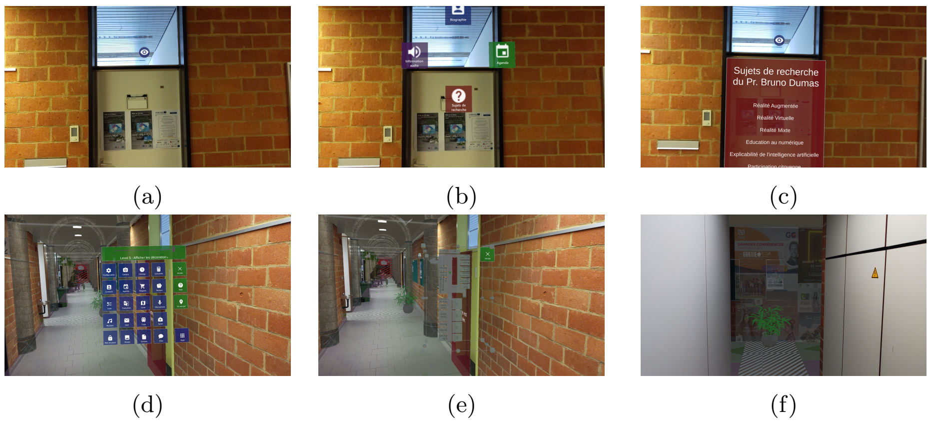

Fig. 4: Illustration of the 4 strategies. 4a, 4b and 4c represent the succession of steps for the situated information on demand by gaze interaction. 4d represents the smartphone with at the top the slider. 4e represents the mini-map available as a situated application. 4f represents the bulletin board with transparency due to the distance to the user.

Strategy 1: Situated Information on Demand with Gaze Interactions. Room indications as described in Section 4.1 convey building related information. Since multiple types of information are available on a restricted area, we hide them inside a gaze based interactive menu. First, an eye icon (see Figure 4a) is visible to the user. If the user wants to check available information, they can open the menu (see Figure 4b) by focusing their gaze on the icon and then select the desired information. This technique has the advantage to keep information situated while still being visible from far away and reduce information clutter. As explained by Plopski et al. [19], using gaze as a mean of interaction is problematic. It is normally used as a mean of observation, and it is therefore difficult to distinguish a user intended interaction. This problem is more commonly known as the Midas-touch problem. According to Duchowski [4], there exist multiple solutions to get around the Midas-touch problem, such as eye gestures, multimodality, boundary crossing, etc. However, the most widely accepted solution being the use of a dwell time, our choice went to the latter with a time of 0.8s.

Strategy 2: Transparency Management for Non-readable Content. Advertising and university bulletin boards need further reflection. This kind of information is typically paid to be displayed, thus there exists a conflict of interest between the user needs to reduce information clutter and the needs of the entity paying for its advertisement to be displayed and visible. The solution considered is to play on the opacity of the information according to the user's distance from the advertisement (see Figure 4f). That way, one can be aware that information is available at that place if their distance from it is considered close enough that the information is therefore readable.

Strategy 3: Reducing or Increasing the Amount of Virtual Elements in the User's Environment. As explained in the previous section, virtual content can be divided into several categories. Each have a different impact on the user depending on the context in which they are included. For example, the decorations could be appreciated by a new visitor but too distracting for an employee. Thus, we designed a slider included at the top of a virtual smartphone to decrease or increase the quantity of categories displayed (see Figure 4d). Each level includes the elements of the lower levels. Five levels were available: 1) Absolutely no virtual elements except the virtual smartphone, 2) only the eye tracking icons for the situated information and bulletin boards, 3) the navigation indications, 4) the social norms and 5) the decorations with the ambient sound. This strategy was also proposed by Regenbrecht et al. [21] as discussed inside Section 2.

Strategy 4: Situated Applications. Some types of information offered by the building may not be situated. That is the case for the help desk answering visitors' questions or the maps placed in certain places as described in Section 4.1. They are however related to the building as a whole. Therefore, we decided to remove information from the virtual environment while still letting them accessible from the smartphone as applications, making them accessible as the user wishes. Here, we describe the concept of situated applications. These are available only when accessing the place they are associated with, and would be removed and replaced by others as the user moves by. We consider these applications and their installation secure.

4.3 Tasks

We asked the participants to find successively four hidden information inside the experiment corridor. This approach lets us explore, on the one hand, users' behavior in a street-like environment by exploring the virtual environment and, on the other hand, to force the participants to test the different interactions proposed by the strategies. An example of requested information was, for instance, the title of the course given at a specific time in a specific classroom, the name of a person, or a date for a specific event. The tasks were designed to force participants to explore and interact across all the virtual environment.

4.4 Variables

Our first objective is to study the evolution of users' mental load between an environment using no strategies, and an environment using the strategies described in Section 4.2. Hence, we chose the NASA TLX form [8] that has six scales to compute the overall workload score of a participant. The standard way of filling the NASA TLX form asks participants to complete the scales and give a weight for each. However, as we wanted to evaluate the impact of the entire environment on the cognitive load through a daily life task, the weight of each scale was predefined and communicated to the participants. Users had to walk around and observe the environment. We put the following order of importance on the scales, from most important to least important: Mental Demand, Frustration, Effort, Performance, Temporal Demand and Physical Demand. Finally, we performed a semi-structured interview to retrieve the participants' feedback. This allowed us to correctly understand the TLX reports and focus on our second goal, that is the ease of interaction and implementation of the four strategies. The questions that structured the interviews were: 1) How do strategies impact user feelings and their perception of reality?, 2) is each strategy useful and properly implemented?, 3) are there other useful strategies? and 4) what virtual elements were the most frustrating?

4.5 Pretests

We conducted pretests to refine the procedure described in the Section 4.7 and to check the concordance with the pilot study described in Section 3. Five members of the Computer Science department tested the experiment. Four of them were participants of the pilot study. They concluded that the virtual environment was oppressing and overwhelming if they must experiment it all day. In regard to the strategies, users considered them as of great interest. Note that they knew the corridor where the experiment took place, thus, they knew where to find some answers during the experimentation.

4.6 Participants

A total of eight men and eight women took part in the experimentation. None of them knew the floors of the building, and none previously participated within the Pilot Study or the Pretests. They were all volunteers, no remuneration was given. The age range was between 21 and 35 with an average of 27.31 years old. Three participants had their high school degree, four had a bachelor's degree, and nine had a master's degree. Ten participants had never tested AR or Virtual Reality (VR). Four played occasionally with VR, one played occasionally with AR and VR and one played regularly with VR. Finally, based on results from Section 3, we further asked each participant how they felt if they were on Time Square based on a photo (See Figure 5). One answered they felt nauseous, one was uncomfortable, six were neutral, four were calm and four were comfortable.

[1] Photo taken by Tagger Yancey IV.

Fig. 5: Picture of Time Square used to determine the participants' level of comfort in big cities[1].

4.7 Procedure

We received each participant individually on the first floor of the building and accompanied them to a meeting room. To begin with, we explained how the experiment would be conducted. First, the participants would go through two experiments, each followed by a NASA TLX form. This part would last approximately 40 minutes. Then, participants would answer questions during a semi-structured interview, which would last about 20 minutes. Before the experiments would start, the participants were asked to sign a data processing agreement and complete a form with personal information (i.e. the information described within Section 4.6). Then, they performed the ocular calibration on the headset, also allowing them to discover how to interact with virtual content as the device displays a floating window with a button to click on to start the calibration.

After this setup phase, the first trial, with the strategies disabled, could start. Explanations were given to the participants as follows: They play the role of a staff member of the building, and they can walk anywhere on the floor except for some rooms. The participants had some time available to get used to the Hololens 2 device and the environment. Four successive questions were then asked to the participant, without any further indication. There was no time limitation, but the investigators would give some clues if a participant felt completely lost. The investigators would also ensure the participant security while also taking notes. Once the four questions were answered, the participant returned to the meeting room to complete the NASA TLX form. Next, the second trial with the four strategies enabled began following the same protocol. The investigators gave explanations on the three active strategies. During the adaptation time, the participant could explore the virtual smartphone capabilities. At the end of this second trial, the participant completed a second NASA TLX form and a semi-structured interview was conducted. Interviews were audio recorded. Not balancing the trials was a deliberate choice, as we did not want participants to have to apprehend the virtual environment simultaneously with the interactions required for trial 2.

4.8 Results

From the NASA TLX forms, we begin by computing the workload score of each participant. This is followed by a Wilcoxon signed-rank test to determine significant improvements in the second trial. Then, we test the dependence between the forms and the participants' familiarity with AR/VR and their comfort in big cities with a chi-square independence test. Finally, we finish with the results of the semi-structured interviews presented inside Section 4.4. Results were obtained with a thematic analysis of the audio recordings.

TLX Workload Score and Wilcoxon Signed-rank Test. Figure 6 presents the distribution for each scale and for the overall workload score. With regard to the mean and median, we observe an improvement for the Mental Demand, the Performance and the Frustration. Conversely, we observe a deterioration of Temporal Demand. To verify the significance of these effects, we performed a Wilcoxon signed-rank test on all scales and on the workload score. No significant results were found, but the Mental Demand seems to tend to a significant improvement (Z = 85.0, p-value = 0.08).

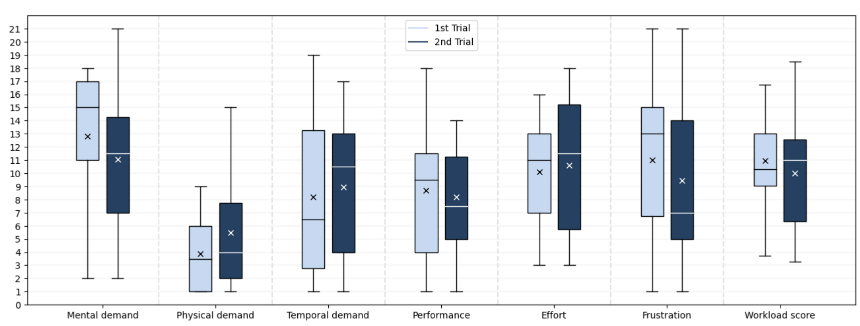

Fig. 6: Box plots of each subscale and of the workload scores of the TLX. First trial results are each time on the left, while second trial results are on the right.

Chi-square Independence Test. We performed chi-square tests to determine the impact of AR/VR technology awareness and comfort level in big cities on each scale and on the workload score. For the former, we observe no significant results. However, we can observe a trend on the performance ($X^2 = 38.67$, p-value $= 0.07$, DoF $= 27$) of the first trial and on the temporal demand ($X^2 = 42.4$, p-value $= 0.03$, DoF $= 27$) and frustration ($X^2 = 41.47$, p-value $= 0.08$, DoF $= 30$) of the second trial. These results seem logical as a better control of these novel technologies reduces the learning time and thus, the frustration. For the latter, similarly no significant effects were found except a trend on the Mental Demand ($X^2 = 53.33$, p-value $= 0.08$, DoF $= 40$) of the first trial. Similarly, it might be acceptable to assume that if the participant feels good in overwhelming cities, they felt good in our experiment's environment.

Impact of the Strategies on Participants' Feelings and Perception of Reality. Finally, we describe the results of the semi-structured interviews. Relative to the first trial, participants felt mainly calm. Nevertheless, everyone described being overwhelmed by the amount of information, while one specified it as intrusive. The participants pointed out the sound within the environment as a major contributor to their feeling. Therefore, 12 participants considered the experience as unusable in their daily lives. 12 of the participants also considered their perception of reality to be deteriorated. In addition, 8 participants found themselves isolated from reality. Eventually, all participants considered the information to be well-placed. For the second trial, results are mixed. 14 participants found their perception of reality enhanced compared with the first trial. However, 8 participants considered the different strategies improved their experience.

Evaluating Strategy 1. As we expected, 15 participants said that this strategy reduced information clutter. 4 said that it is most useful when knowing where to find the information. This last statement is supported by 8 participants saying that it negatively hides the information when searching for it. 9 said it structured the information, allowing them to easily navigate and isolate the wanted information. Finally, 5 participants said the gaze interaction icon was placed too high, and two participants would have preferred another way of triggering the interaction than the dwell time.

Evaluating Strategy 2. 10 participants stated that they found bulletin board transparency useful, while 3 were against this strategy and 3 had no opinion. 12 participants explicitly said that it may trouble them not being able to see information availability while searching for it from far away. One participant stated that universities' bulletin boards are not equivalent to advertising panels, and 7 said the technique could benefit from an icon indicating available information when too far away from the user. Finally, 12 of the participants said that the moving bear drawing attention was not problematic, however the manner in which the advertisement is displayed was.

Evaluating Strategy 3. 9 participants mentioned that they had difficulties in interacting with the slider. During the experiment, we observed that most participants selected the third or fourth level of information because they did not see any difference between the two while experimenting. They however noticed that these levels mute the audio. 5 expressly wished for a separated way of muting the audio, while 2 participants stated that they kept a high level of information because they feared they would lose some otherwise. Also, 7 explicitly said they would have preferred an alternative way of interacting where they would be able to turn on and off the chosen information level as they pleased. All participants liked the concept and the control it gave them over the environment.

Evaluating Strategy 4. 13 of all participants found the idea behind situated applications useful. However, 5 were concerned about security issues and their privacy, even though we focused on security during the phrasing of the question. 7 stated that it was useful since it created a pattern to access and find available information. Finally, 2 participants said that the applications should stay installed and that only their content should be situated, thus users would know how to use the applications and what information would be available.

Ideas and Frustrations. Before finishing the interviews, we requested each participant to classify what were the three most frustrating things they experienced during the experiment. Moreover, we asked them if they had any ideas for improving such environment. Recurring answers for the former were 1) mute the ambient sound that they considered as noise, 2) remove advertisements occluding the view, and 3) improve the interaction for the different active techniques. For the latter, some expressed the need for more interaction with the situated information, as being able to grasp it, resize it or make it scroll. Others would have wanted the ability to access the desired information without having to walk or to save it for later inside the map application. Finally, a participant said that daytime could be used in order to filter out unneeded information.

5 Discussion and Future Works

Participants' feedback shows that an unmanaged and unconstrained augmented world is difficult to withstand, thus elaborating strategies to handle augmented information clutter is a vital need. The strategies proposed in this paper were appreciated. Participants' mental demand and perception of reality tend to be improved as expected. Decreasing the amount of virtual situated information frees the user's environment, while the slider allows them to specify their preferences depending on their needs. For instance, a participant said that, in a museum, they would typically set on the last level to fully experiment the virtual content but in their daily life set it on a lower level to prevent distractions. The slider allows each user to specify their preferences rather than sharing a common level across all users. In addition, situated applications offer users quick access to information specific to their location and an easy way to grasp its spatial organization. As for bulletin boards, as they are advertisements that are paid to be displayed, participants understood that the same technique as the gaze input could not be applied. Despite the majority of participants finding the transparency strategy useful, they were not fully convinced by the strategy. First, it hides information, and last, bulletin boards were not the most obtrusive elements.

Nevertheless, it is difficult to determine the strategies' efficiency, as no statistically significant effects were found. First, we observed frustration and mental fatigue for the participants who had difficulty with the interactions. A small training session outside the experiment could prevent this in future works. Second, the short duration of the experiment did not allow the participants to properly overcome the novelty effect of trying an AR headset. For instance, a participant said they selected the fourth level on the slider so that the sound could be stopped while keeping the maximum amount of virtual elements to get the most out of this innovative experience. As far as the authors know, the minimum adaptation time to correctly study users' behaviors in pervasive environments is unknown. We are planning to conduct a longer experiment once the strategies are refined to study the evolution of the participants' cognitive load. Last, while it was not prohibited to use physically available information to guide or to answer questions, participants prevented themselves from doing so. An explanation given by a participant is that they were not sure if the virtual information was associated with the real location.

We now discuss the implementation of the different strategies and their ease of interaction. For strategy 1, some participants recommended to directly display the different categories of information (as can be seen on Figure 4b). The current state increases the necessary interaction time significantly. This suggestion raises the question of the right balance between information clutter and the number of interaction steps needed to access available information. For frequent use, two successive dwell times of 0.8 seconds seems to be too burdensome. An alternative would be to display a reduced level of information and then, let users keep and expand only what is desired. For strategy 3, participants wanted more freedom in the selection of what is displayed and what is not. Isolating visual and audio controls is also crucial. Thus, rather than a slider, a better solution would be a toggle for each different category of audio and visual content. Therefore, users would be able to select only the ones they want. A toggle to enable and disable augmented reality content without changing all the specified preferences would also be required. This result is consistent with Lu et al. [14] stating that participants want to be relieved at times. For strategy 4, some participants want standardized visuals and interactions, thus pushing for situated content rather than a situated application. The help application should be implemented as a chatbot (i.e. Siri, Alexia, ChatGPT, etc.). Depending on the location, the application should have access to a dataset of information specific to the place to help it answer users' questions. Answers presentation must be explored in future works, but should not be limited to oral answers. The map application must indicate information position relative to the world and let the user gain access to it without having to move. One participant mentioned that they felt like they were regressing back to a time before smartphones existed, when you always had to go to different places for information. Eventually, the map must guide users to locations, but only on demand. About strategy 2, participants asked only for adding an icon when the boards disappear. As said above, participants considered this strategy as not really mandatory, even if they understood the interest to free the view when unreadable. Some participants said they are accustomed to advertising panels and do not pay attention anymore.

Finally, while most works in PAR study context-aware approaches, as stated by Grubert et al. [6], manual sporadic user interactions are also needed. Therefore, our approach first tries to give control back to the user. It is essential to reduce the frustration and fears caused by unexpected changes by ensuring user control. PAR environments need to stay transparent, with user's agreement and acknowledgment, by mixing automated and interactive approaches.

6 Conclusion

In this paper, we presented information clutter techniques in case of a Pervasive Augmented Reality (PAR) environment. We began by conducting a pilot study to highlight potential problems conveyed by Matsuda's illustration of an augmented street inside his video called "Hyper-Reality" [10]. This pilot study led us to define four strategies to control information clutter in an augmented environment:

1. Using gaze direction to expand situated information panels;
2. Applying some transparency on virtual information depending on the distance to the user;
3. A slider letting users specify their preferences over the amount of virtual elements displayed;
4. Situated applications (help and map) integrated in a virtual smartphone.

Finally, we conducted an evaluation of these strategies in a street-like PAR environment where virtual information came from various sources. Results are the following: 1) The experience without any strategy to handle information clutter generated negative feelings with our participants, in particular regarding the prospect of living in such a world, 2) participants appreciate all the strategies except the second one to reduce the cognitive load and 3) some usability aspects of all different strategies presented in this paper would need to be refined further. A strong recommendation is the ability to make information available anywhere to the user. In the future, we wish to work on how to better design these interactions and how applying specific context-aware solutions can support these strategies.

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