Navigating the Virtuality-Reality Clash: Reflection and Design Patterns for Industrial Mixed Reality Applications

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ABSTRACT

Creating Mixed Reality applications poses distinct challenges for development and design. One of the challenges is designing Mixed Reality application-specific experiences in the wild. In this paper, we present a structured reflection approach to revisit projects from the past. In applying this structured reflection to the data collected during a nine-month industrial project, we unveiled the Virtuality-Reality Clash. To generate a sufficient data corpus, we structurally analysed git commits, tickets, emails, handwritten notes, and weekly snapshots of the 3D designs. The clash could be narrowed down in our data corpus to the situations in which we were fusing the real environment with the virtual content. Finally, we could find five design patterns for MR experience. With these patterns, we aim to help developers and designers of MR applications identify situations where Virtuality and Reality clash and propose approaches to address them.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; **Mixed / augmented reality**; **Interaction design theory, concepts and paradigms**.

KEYWORDS

Mixed Reality, Augmented Virtuality, Design Patterns, Virtuality-Reality Clash

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1 INTRODUCTION

Designing Mixed Reality (MR) systems is challenging, and more reflection and communication between researchers and practitioners are needed for the following three main reasons. *First*, the resulting MR environment may not fully support the MR designer's original intent, since *the physical environment where the system is deployed can be restricted*. Thus, it can hinder the unfolding of the intended experience to the extent that it may not be accessible to the users. Börsting et al. [6] framed it as the "relevance of the physical world requires [MR] user interfaces to comprise virtual and physical artefacts" and underlined the importance of the real context to provide the virtual content (see also [27]). Oppegaard [40] phrases the complexity of mixing reality and virtual content as an "ultimate challenge" to MR creators, who need new approaches and supporting theory. This is a multi-faceted design tension we chose to refer to as the Virtuality-Reality Clash. Although this clash has been known for years in research, and among MR creators, we know little about how to handle the related issues in terms of approaches and Design Patterns.

Second, the current design approaches and attitudes to design often encountered in MR system construction processes are dominated by *engineering priorities*. In other words, system creation is viewed mostly as an engineering task. Still, design decisions must be made along the way, and a design conscience and associated reflective practice may emerge during the process. Building MR and Virtual Reality (VR) (both often grouped into XR) applications can often be regarded as engineering because two-dimensional sketching practices do not work well in XR; it is often perceived as easier by an XR developer to sketch using 3D programming tools for which they already have the skills to use, and the system construction is regarded as a linear iterative prototyping process.

Third, the three-dimensional nature of the system and expensive 3D sketching compared to, e.g., 2D pen-and-paper, makes it *hard to communicate and reflect on the design stages and alternatives*. Scholars have proposed various ways of prototyping MR (e.g., [9, 47]), but to our knowledge still no distinct prototyping approaches have been widely adopted yet. Given the engineering-dominated practice and the preference for iterative development at the expense of sketching, annotated sketches of intermediate designs may not be available, which hinders practitioner reflection and communication with other practitioners.

We faced all these challenges in the design experience during a 9-month-long industrial project while iteratively creating an MR system for occupational safety training intended to be deployed at around twenty sites worldwide by a multinational corporation. The process started as a software development project, and thus, we used software development management tools to structure it. This approach served well at the project's beginning, when we were still exploring the basic technology and issues in applying it. Still, during the project, we encountered that developing MR systems finally comes down to making many design decisions. To foster being conscious of making design decisions during our work, we collected the traces left by our creative process in various documentation systems and the imprint on our understanding of MR design and development by personal reflection. We are convinced it is important to share not just the findings of this process, but also to encourage fellow software engineers to embrace design thinking and apply retrospective tracing to the evolution of their design.

One approach to sharing findings on design problems and solutions is Design Patterns. Many design communities and software engineers have picked up this concept originally proposed by Alexander et al. [1], and a large body of Design Patterns (and guidelines) can be found for VR and MR [6, 12, 15, 21]. Among others, Dabor et al. [8] have proposed Design Patterns to reduce the users' cognitive load and suggest making the system "intuitive" and the interface easy to use "for both novice and expert [users]". Gavish et al. [17] proposed Design Patterns for training maintenance and assembly tasks in MR. The authors also advise others to follow their patterns and reason for it. Thus, we build on the established practices of deriving Design Patterns to share findings on design problems in MR environments for industrial contexts. What is lacking in both contributions and many others is an exemplification of how this impacts the development and design of MR systems and guidance on how addressing these impacts might look.

In this paper, we propose a structured reflection technique based on reconstructing successive evolution stages of our designed artifact. We retrospectively identify each major design stage and understand it in the context of team communication documents produced during the process based on emails, tracked development issues, the system code, and its evolution. We then report on the results of our reflection in a Design Pattern format and subsequently examine the relationships between these emerging patterns, especially at the tension along the Virtuality-Reality Clash. Our contributions are thus threefold: (1) a method for structured reflection based on a linear and non-linear re-enactment of artifact evolution, (2) five proposed Design Patterns in MR application design, and (3) implications for such design in the future. Compared to previous work that primarily considers the user perspective, we build on MR designer/creator perspectives in developing an MR project with industrial partners.

2 RELATED WORK

According to Alexander et al. [1], Design Patterns are entities that, in their entirety, describe a design language. Each pattern focuses on one challenge, which usually emerges as a "set of conflicting forces". The patterns do not propose concrete solutions to balance these forces but define a set of qualities that designers should consider addressing the challenge. Since they are part of an individual design language, these qualities are addressed based on the individual designer's (MR creator in our case) understanding of good design. MR relies on advances in computer science since this field provides access to MR creators' materials by offering frameworks, development environments, and algorithms needed to create mixed environments. We have chosen the conceptual framework of Design Patterns to appeal to designers working within computer science, but at the same time communicate also to Human-Computer Interaction (HCI) folk. Design patterns have been adapted to the computer science audience and became well established since they were proposed by Gamma et al. [14]. The original proposition of Design Patterns by Alexander et al. [1] focusses on architecture. In a similar manner, MR design requires MR creators to consider technological constraints and best practices in implementation and standardisation while being in a creative process which aims to form a meaningful environment. Scholars have already introduced design recommendations for MR design for different fields of use (e.g., [11]), different target groups (e.g., [31]) or along individual use cases (e.g., [22]). Others have already tried to provide a more general perspective on the topic (e.g., [6]). In their contributions, scholars emphasize challenges related to fusing reality and virtuality to different extents but do not focus specifically on designing for this fusion process. Consequently, this contribution aims to equally address both communities that shape MR, the HCI and design research community and the computer science community. Therefore, we employ the concept of Design Patterns, which are known in both communities. According to Alexander et al. [1] the context, in which each pattern is used has to be defined. The patterns we present in this work all have the context appearing during the creation of MR applications for industrial training.

Like Gaver and Bowers [16], who propose Annotated Portfolios as a bridge between design research and other science disciplines, this work takes from working approaches of computer sciences and uses the resulting data to introduce the fuzzy body of the material presented by the Virtuality-Reality Clash and to propose Design Patterns which are intended to help scholars to work with this material properly. In contrast to Annotated Portfolios, Design Patterns aggregate solutions over various artefacts or aspects of an artefact, which we employed to characterise the design of our MR application. Still, in the spirit of Annotated Portfolios (see [16]), this contribution aims to understand creative work as the creation of a rich source for reflecting on design decisions and understanding various materials in context.

3 METHODOLOGY

Our main goal was to understand better the unfolding of the Mixed Reality (MR) project to create an occupational health and safety training with an industry partner, formulate emerging challenges during the development and design, and reflect on the design and development process. Specifically, the purpose was to investigate specific MR-related aspects that influenced the course and the project's outcome. We wanted to recall as many situations on the project course as possible. Therefore, we aimed to collect all data available on the project. We revisited the archived project in the software

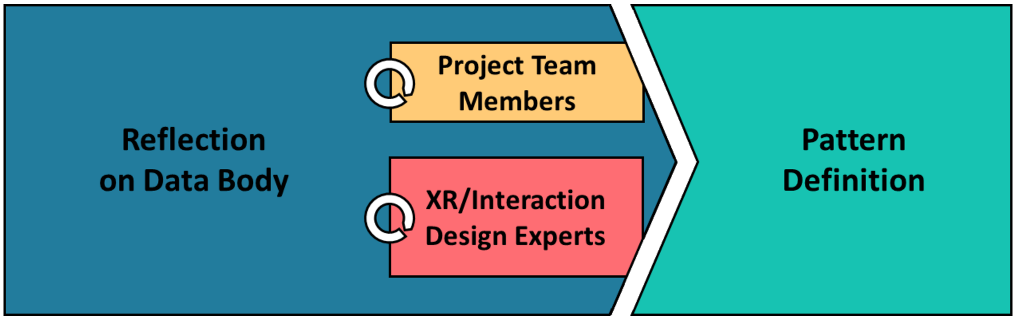


Figure 1: The structured reflection approach: While reflecting on the prepared data (blue), we iteratively consulted Team Members (yellow) and Experts (red) to discuss findings. Based on this reflection, we defined five Design Patterns (green).

development tools, communication on the project, and documentation (digital and physical). In detail these data are: (1) 314 Git commit logs (software versioning tool), (2) 132 Tickets (i.e., task assignments), (3) 53 emails, (4) a few notes for documentation in the project team's workspace, and (5) weekly snapshots of the 3D design by checking out the last commit each week in each active branch, selected scenes with changes, and added images from within each scene (each of the four walls and the floor) and one 3D perspective (from the same position in each scene) to the data. These data were extended by (6) personal memories and reflections, recalled by details in the materials during the data acquisition and processing.

The MR training application is conceptualised as adding to the toolset for training employees on safe behaviour at the workplace. It covers several themes, from manufacturing and maintenance settings to an office-themed environment, and was rolled-out to the partner's worldwide facilities after finalising the development. The selection of the content relevant to the application's training, development, and design was driven by the experience of the industrial partner in collaboration with our development and design team. The training is implemented for Microsoft HoloLens and can be considered as MR on the Augmented Virtuality side of MR (see [35]). Because the application is just one of a set of tools for occupational health and safety training and internationalization reasons, we implemented it so that the trainee (i.e., the application user) has to communicate with the trainer on the side. Seeing the trainer as part of the environment fosters this communication and allows the trainee to be guided while exploring the mixed environment.

3.1 Data Extraction

To analyse git commit logs, we exported them from the git repository, pseudonymised the committer's name, clustered them by date, and ordered them chronologically. We annotated the commits by adding colour coding indicating which specific development task has been addressed in the committed code. These annotations range from scene topic indicators, e.g., "office", over interaction approaches, e.g., "alerts", to providing the technological basics to deliver a mixed environment, e.g., "MRTK", referring to the Mixed Reality ToolKit for HoloLens. We created these codes based on the team's wording established to discuss tasks during the project. We extracted the ticket ID, name, and date from Jira to analyse tickets. Again, we pseudonymised names, clustered the tickets by date, and arranged them chronologically. We used the same annotations as with the git commit logs to add information about the specific development task assigned to the ticket. To analyse emails, we extracted all emails between the project lead and the customer and emails between other team members to the project lead. Handwritten notes, content from the project workspace, and reflections have been added to the mail section. We decided to cluster these data since they require a more comprehensive analysis. These data are usually written text containing information about specific people (we pseudonymised), information that needed to be added to provide the data context and semantic information. Also, these data consist of various data formats, such as PDFs, Excel sheets, screenshots, etc. After ordering these data by date, the same annotations as for the git commit logs and the tickets have been used to indicate the content. To analyse the weekly design snapshots, we checked them out from the git repository, opened the 3D development platform (Unity), and took the six pictures from predefined positions in each scene that have been worked on during the week. To identify whether and in which scene there have been changes during the week, we consulted the commit logs, which, among others, log the names of the files which have been edited. We then annotated the visual changes made since the previous week based on the previously prepared project documentation, correspondence, and personal reflections by examining each 3D scene in detail.

3.2 Data Analysis

The structured reflection approach (shown in Figure 1) we applied, consists of two steps. First, we reflected on the data body ourselves and consulted experts within our research groups, and second we derived Design Patterns. The reflection was performed by browsing the visualised data corpus with the aim to remember critical situations during the project in detail. Critical situations in our context are those for which we found many data points in a short time span, those which working on took a long time span, and finally those, where during reflection we were able to relive the situation emotionally. To further analyse the extracted data, we conducted discussion sessions as needed with two members of the project team and three experts in XR and interaction design. Each discussion session was conducted by the project lead and one expert, and

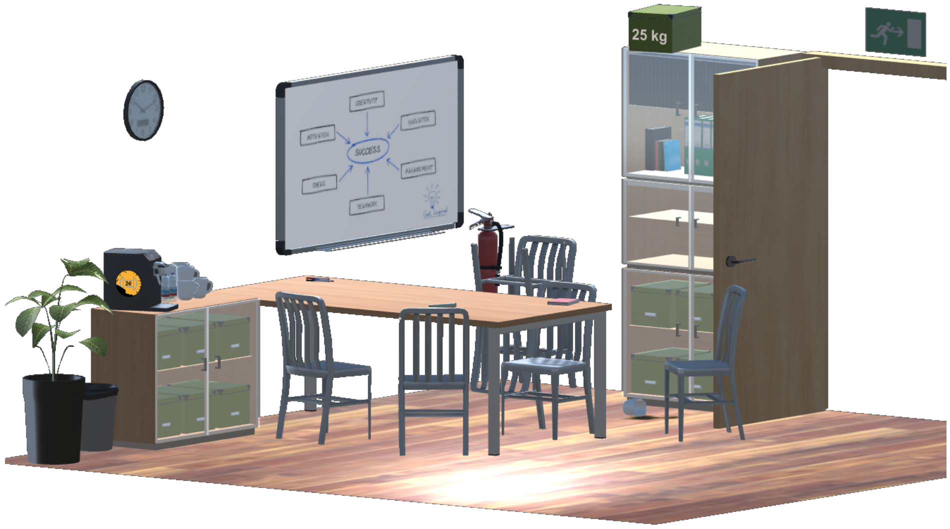


Figure 2: An office themed scene with a coffee maker featuring a yellow sticker stating when its electric insulation periodic check was completed (round yellow label on the left) and the green box on top of the shelf (top right) with a 25 kg label.

was about one to a few critical situations. In these discussions, the visual representation of the data corpus was directly modified and extended, and no further notes have been taken, to establish an open atmosphere. After each session we refined the modifications and extensions, or if they were done exemplary, rolled them out to the whole data corpus.

The two members of the project team have experience in computer science and are familiar with the use of the 3D development platform (Unity) for creating XR environments. Therefore, they also have already been confronted with making design decisions in this area, among others, on interaction design and user experience design, and in implementing XR applications accordingly. We consulted both team members while analysing data points created by them or related to tasks they implemented. They contributed with their reflections on their work invoked by the presented data points. The XR/interaction design experts we consulted have a background in computer science and experience in creating XR content and implementing interaction concepts beyond this project, and have been asked to add more details to critical situations. They reported their current understanding of the data and contributed with reflections on the design and related theory.

While the clash of reality and virtuality had already unconsciously structured the discussions at the point of the discussion sessions, the peers' contributions were necessary to narrow down the very nature of these situations and pinpoint their shared attributes to the Virtuality-Reality Clash. Finally, we employed a thematic analysis [4] to extract five themes that emerged during the discussions. As a result, based on these five themes, we derived the five Design Patterns presented in the following section. For each pattern presented, we will first describe the problem by the forces which constitute it. Based on that, we introduce the challenges we faced and the solutions we found to address them. In these two sections about each pattern, we refer to data points listed in the appendix[1] in brackets, for example (SaA01). These data points inform our pattern, summarised in the following pattern statement.

4 DESIGN PATTERNS FOR MIXED REALITY EXPERIENCES

4.1 Signifiers and Actual Affordances: To Take up the Inheritance or Not

4.1.1 Problem. When using signifiers and implementing actual affordances, we encountered three "forces". On the one hand, we must guide the users' attention to signifiers that hint at actual affordances, i.e., allow the user to interact meaningfully. On the other hand, presenting many signifiers challenges the intended user experience by possible occlusion of content and clutter, and can conflict with the intended overall design. Finally, some actual affordances require deviation from the real world's example and visual storytelling on selected signifiers. These forces constitute the ***problem of semantic occlusion***, which needs to be addressed in MR design.

4.1.2 Context. If an MR environment would offer all the interactive functionality of its real-world counterpart, e.g., all drawers can be drawn, users might get overwhelmed with the many opportunities to interact in the scene. When discussing how to highlight the artefacts that matter for our applications narrative, we were exposed to the forces appearing in the tension field between inherited real-life affordances and implemented actual MR affordances.

We encountered these forces when placing a yellow sticker indicating the schedule for periodic checks of electrical equipment, e.g., a coffee maker (Figure 2 left, SaA01). In our industrial context, stickers are legally required to indicate the operational safety of

[1]In the digital paper format, references to data are interactive hyperlinks pointing to the respective section in the appendix.

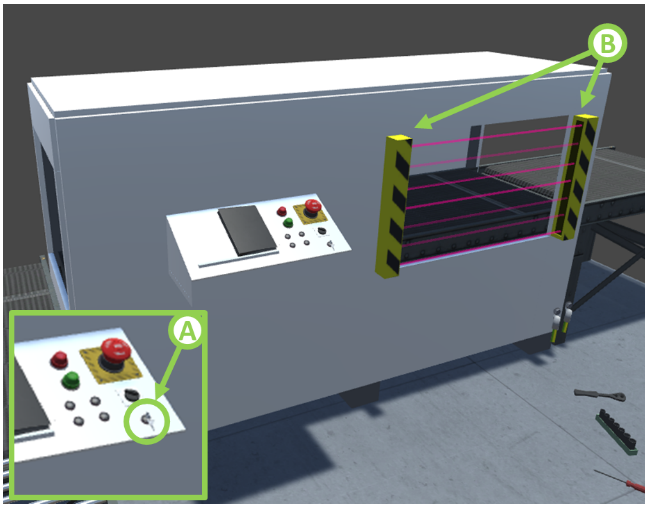


Figure 3: The light curtain Ⓑ and the key switch on the control panel, right below the red emergency switch Ⓐ.

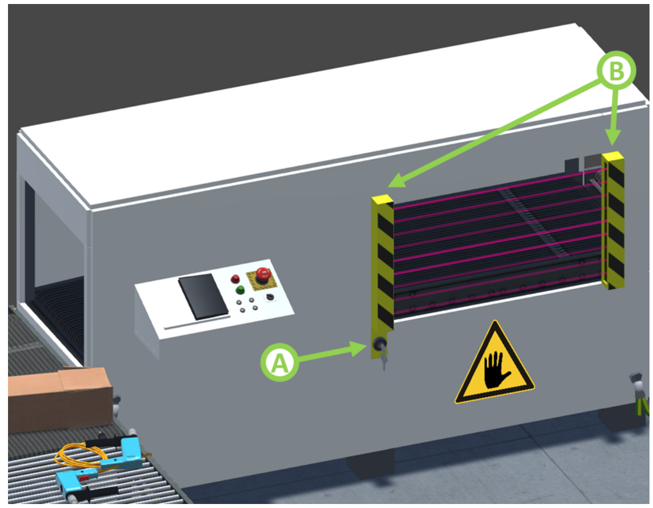
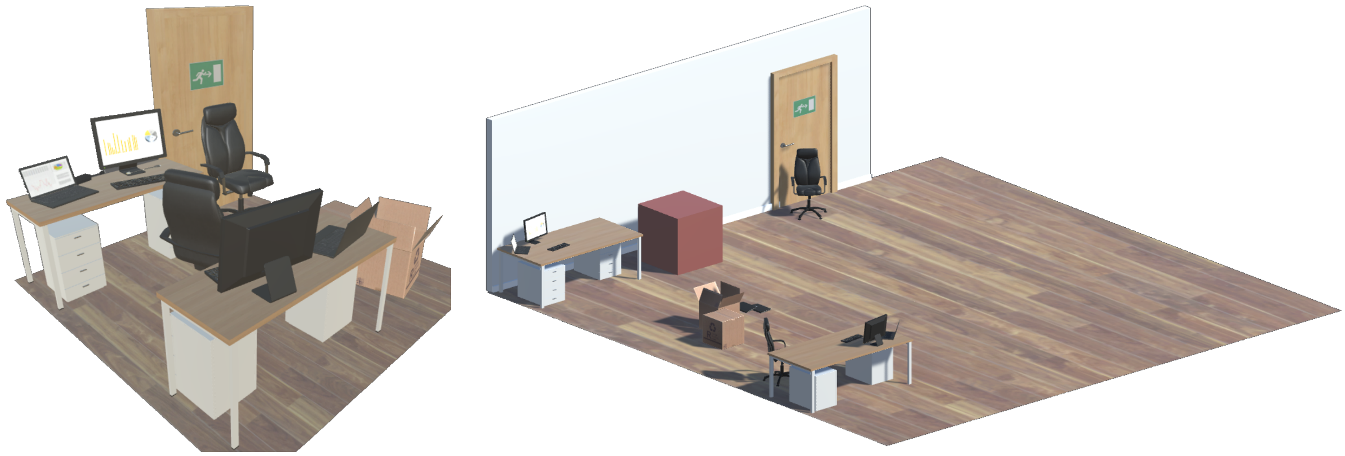


Figure 4: The light curtain Ⓑ and the key switch just right below on the left casing and on yellow background Ⓐ.

electrical devices, and employees should check these stickers before using the devices. The stickers are approximately the size of a two-euro coin and are often placed in a protected position since exposure would lead to peeling it off too quickly when the device is handled roughly. Hence, they are often glued to the back of devices, next to where the power cord is connected. This tension between forces is further exemplified by the risk of objects stored above the head falling down and potentially hitting someone. Putting a storage box on top of a shelf would imply that the trainees have specific knowledge we can not presuppose. Therefore, the storage box has been put partly over the edge of the shelf, emphasizing the risk of it falling (SaA01). This example also shows how signifiers fade in the multitude of interactive objects in the scene, which is intensified by the box being high up and on the periphery of the field of view. If trainees did not draw their attention to objects, they could not identify this risk. Another situation we designed to indicate that safety devices need to be switched on to provide the intended service was based on a machine with a light curtain, i.e., the safety device consisting of a row of light barriers. The aim of depicting the light barrier was to educate trainees on the importance of not bridging safety devices when the machine is in use. This safety device can be switched off with a key switch which initially was placed on a control panel with other switches (Figure 3 Ⓐ), as it would be in the real world counterpart. When inspecting the scene in this design phase, we encountered a distance between the two objects, the key switch (Figure 3 Ⓐ) and the light barrier (Figure 3 Ⓑ). It would require the trainee to have very specific knowledge of operating the depicted machine, which was not designed after a real-world counterpart. Thus, it would be very hard for trainees to identify the key switch as a signifier for an actual affordance on the control panel, since it holds many signifiers.

4.1.3 Solution chosen in our project. During the course of the project, we decided to deviate from what users actually know based on their real-life experiences, when designing signifiers for actual affordances. As shown in Figure 2 (left), we did not place the safety check sticker on the back of the coffee machine, but on its side, while scaling it to approximately hand-size and making it is easier to spot. Furthermore, we slightly rotated the machine (SaA07 and SaA08) to make the label stand out more in the environment. Another conscious deviation from the physical reality that we employed to highlight the affordance of an artefact, depicts the need for carefully interfering with the familiarity of signifiers: In addition to the signifier presented by the box stored above head-height already being partly over the edge, we placed a weight label as an additional signifier on the cardboard box's front (SaA02, SaA03, SaA04, and SaA06). The sharp edges of the letters clearly deviate from the overall appearance of the scene (Figure 2 top-right), but the weight label still can be logically incorporated into the overall experience. The control panel (Figure 3 Ⓐ) depicts another facet of this Design Pattern. Even though in real-world setups, control devices are usually grouped in a panel and only trained personnel are running machines, we needed to convey the connection between the key switch and the safety device. We therefore employed the proximity Gestalt principle, i.e., perceptual grouping [43] used also in MR design (e.g, [15, 55]). Hence, during the course of our design process we moved the key switch from the control panel, where it would be expected, directly next to the safety device (Figure 4, SaA05). Furthermore, we gave it the same background colour as the light curtain casing, visually connecting those two elements even further, and enlarged the key switch to let it stand out more.

4.1.4 Pattern Statement. When designing virtual objects depicted in MR applications, creators often follow the objects' real-world counterpart. These objects depict various signifiers inherited from the real-world. Some signifiers are important for the application and afford functionality, and others are there to depict objects in their usual role but with no interactive semantic. Users need to be



(a) (b)

Figure 5: Early office layouts for testing the influence of dimensions on the MR environment. *(a)* shows a design with a 3×3 m² base area, among others, equipped with two work desks to show various hazardous situations, and a blocked emergency exit. *(b)* shows a design with an 11×11 m² base area with the same objects in a similar arrangement. Additionally, there is a red cube with a side length of one meter to estimate sizes in the scene.

able to distinguish between those two kinds of signifiers to interact as intended by the application purpose. MR creators must indicate which objects matter to the user by making them stand out more from the rest of the MR environment.

P1: MR creators must intentionally deviate from their design language to depict actual affordances, while consciously harmonising the deviations with the overall appearance of the MR application. Consideration has to be given to the impact that these changes can have on the user experience and how MR creators can compensate such effects.

4.2 On Dimensions: When the Right Size Matters

4.2.1 Problem. Defining the right size in MR design is shaped by two "forces". The first refers to the setup of a mixed environment on top of a real environment, i.e., suitable physical and digital sizes must be defined. The second one refers to the perception of the size of each individual object. These two "forces" describe ***the problem of defining sizes on a macro and a micro level***.

4.2.2 Context. One requirement on the application was to use it in as many physical places as possible, i.e., to use the application in the various plants of our customer all over the world. In other words, we were tasked with finding the most economical dimensions of our use case.

Initially we worked with the hypothesis that the less area the MR application requires, the more physical environments potentially can be employed, since trainings often take place in smaller meeting rooms with limited space for using the MR application. Hence, we perceived a tension of forces in the process of finding the most suitable dimensions. As MR creators, we had to balance using the MR application in small environments and the desire to build a complex mixed environment telling a complex narrative. At the time we were exploring the smallest dimensions, we could work with, we were mainly designing office environments and the emerging scenes were employed for making various basic decisions, among others the dimensions. For one of the two office scenes, we had to put a desk of about two meters width next to an emergency exit of about one meter width. This arrangement would require at least one wall of three meters width (ODs03). The resulting mixed environment was very small and crammed with objects (Figure 5 *(a)*). This effect was amplified by the small field of view of the Head-Mounted Display (HMD), which was restricting peripheral sight. It was impossible for us to observe the environment in its entirety, without "virtually bumping" into an object or through the wall outside the scene (Figure 6 *(a)* and *(b)*). When we realised that we were stepping into virtual objects, we always felt a sense of interference with our bodies, a perceived violation of our bodily integrity (see [49]). This can be expected to be higher if users associate the body they see with their physical body [38], which is the case in our set-up.

Furthermore, it does not necessarily imply that more space is automatically better: We experimented with other dimensions to explore how the mixed environment unfolds in physical rooms with walls of about eleven meters width. Here, we encountered that putting the single artefacts too far from each other makes it hard to relate them with other artefacts in the same mixed environment. As shown in Figure 5 (b), the artefacts became detached from each other and the scene's coherence fell apart (ODs02).

Another design alternative, we briefly considered for exploring how we can be more economical in the use of space, was to reduce the size of all objects in the scene. We expected that the smaller objects would leave more space for the trainees and therefore might reduce occasions of "virtually bumping" into artefacts. This led to a shrunken scene in which trainees "could peek over the door into the room" (ODs05). The unusually small size of the objects gave us

(a) *(b)*

Figure 6: The users' perspective within the office with a 3×3 m² base area. (the top view, field of view depicted with blue lines) To see as much as possible from the scene rendered in by the HMD, the user needs to stand in the virtual office chair. The perspective in *(b)* is the one of this user through the MR-HMD and illustrates the small field of view.

the impression of "the entire interior [looking] like a doll's house" (ODs05). Similar to a doll's house, this induced an impression of being in control of the whole environment. Furthermore, we noticed that the reducing object sizes can increase their perceived fragility, similar to furniture in a doll's house. The occupational health and safety training aims at reproducing certain aspects of reality: It attempts to put the trainees into a role they would have in their real-world work environment, which is none of control over an industrial setting. Furthermore, we wanted to encourage trial and error to explore the mixed environment, which is prevented if the artefacts are perceived as fragile.

4.2.3 Solution chosen in our project. To be able to judge whether dimensions of the area are right for providing a mixed environment and based on the extremes that we encountered early on, we decided to "test 4×4 [m^2] and increase step by step if necessary" (ODs04). Later in the design process, we fixed the dimensions to the agreed on maximum of 5×5 m^2 (ODs04, ODs01).

These dimensions allowed us to equip the space with virtual artefacts without overcrowding it and still leave some area dedicated to the users, while also allowing to use it in a sufficient amount of rooms. To better use this space, we later on optimised the available space by moving objects closer to the walls, leaving more space for the trainees (ODs06, ODs07, also DfM14). Since we were working with fixed dimensions, we decided to hand out a user manual to the trainers who are orchestrating the training sessions and want to use the MR application. In this user manual, we collected the basic requirements our MR application has on the real-world environment, to allow users to take the necessary measures to prepare the environment. We did refrain from changing (i.e. shrinking) object sizes to avoid the doll's house effects. Using the correct object size, but also other aspects of geometric consistency, as described by Rolim et al. [45], fulfil the users' expectations on objects and helps to accommodate in the environment, for example by estimating distances based on object sizes [41]. Furthermore, it also can influence the way users perceive their role in the application, since the size of objects in their environment, similar to what scholars (e.g., [39]) describe for distance, put users in to a mindset.

4.2.4 Pattern Statement. When a real environment is superimposed with virtual content, the resulting mixed environment's dimensions rely on the dimensions inherited from reality. This challenges MR creators to incorporate a range of potential dimensions in their application and take care of how dimensions influence the user experience. Thereby, MR creators will want to avoid users colliding with virtual or physical objects. The size of the mixed environment often needs to be defined early on in a project, since this is the basis for considering the arrangement of virtual content. Not only do the dimensions of the virtual content impact this decision, also the number of users and incorporated real objects affect the space's dimension.

P2: MR creators have to define guidelines regarding the real-world dimensions needed to use their MR application. They can inform the MR users left in charge of setting up the mixed environment, in various ways: Among others, the MR creators can hand out a manual, depict the guidelines in the set-up process or even enforce these rules by blocking unsuitable environments. In addition, the suitable size of virtual content, not just the dimensions of the overall mixed environment, also matters to put the user in the intended role.

4.3 Design for Movement: More Than/Beyond Input

4.3.1 Problem. The integration of human movements in MR applications is challenged by three "forces". First, the amount of used

Figure 7: Final design of the office scene. The dimensions are fixed to 5×5 m^2 and space is provided to not be forced to walk into virtual artefacts when exploring the scene.

digital objects can inhibit or support moving through the mixed environment. Second, when moving triggers software behaviour, this trigger needs to be fired robustly. Finally, users need to be aware of how they control system behaviour, e.g., by being taught about it beforehand or by finding out in a learning-by-doing fashion. These forces can be subsumed to ***the problem of movement in MR as a multi-faceted interaction.***

4.3.2 Context. Bodily activity in general is known to shape the way humans understand their environment, and therefore also how they learn [51]. Hence, while developing and testing our application, we had to handle the forces impacting the design when incorporating the movement of the users (DfM01). To encourage movement in the mixed environment, we decided to incorporate both, the users' full body input but also more subtle hand gestures. While we had to define how to work with both, we figured out that users also need to be informed about how to use their body to consciously control the application. Among others, we encountered that "[i]nstructions must explain how to use elevator and portal" (DfM13), to be able to interact with their environment purposeful. This was constrained by the fact that our application is used in different countries and the requirement to use the application "out-of-the-box" without any adaption to local language. Hence, we aimed to not communicate with the users using a specific language, written or spoken (DfM02). Also, we were aware of the fact that other means of communication aside written and spoken language, such as the visual the design of the scene, for example, the selection of furniture, differ based in different cultures. Nevertheless, this app is tailored to the customer's company culture and also informed by our visit to the customer's plant. It is supposed to enhance the corporate culture, but supplements, rather than replaces, existing training methods, allowing flexibility to reflect local practices. Early on in the development and design process, we figured out that the available space to move is influenced by the amount of virtual and real objects within the mixed environment (see P2). To not overcrowd the mixed environment, we were looking for a solution to change the virtual content without confusing the users by randomly loading new content. Hence, we were looking for a mechanism which allows users to consciously trigger the loading of other virtual content.

4.3.3 Solution chosen in our project. During the dissection of this pattern's forces, we considered various approaches. Among others, we discussed "point & teleport" as introduced by Bozgeyikli et al. [3], where users trigger a trajectory holding a button and are teleported to the location pointed to when releasing it. We concluded to place a portal in the scene, shown in Figure 10, with which the users can navigate to the new virtual content (DfM03, DfM05, DfM10). These forces unveiled by levelling between simplicity and robustness surfaced when we were mitigating unintentional interaction by unconsciously entering the portal. This usually happened, when users entered the portal while stepping backwards, (see Figure 8 ①). As a result, new virtual content was displayed suddenly, which led to confusion and broke the user interaction flow. We saw the need to inform the users on their input and give them time to reflect and react on it (DfM04, DfM07, DfM17). We also included implicit interaction, based on employing the change of the users' position to trigger an event. By design, we opposed the conscious body position based input described before, to inform users of certain areas which are not to be entered, since they pose risk to humans (DfM12). One such area is the driving path (see Figure 9, where, among others, forklifts drive with 10 – 20 km/h. Entering these areas is connected to the risk of accidents with severe injuries. Another issue we were facing was informing the user on how to use hand gestures. We decided to introduce short "videos [which] play on gaze [i.e., when

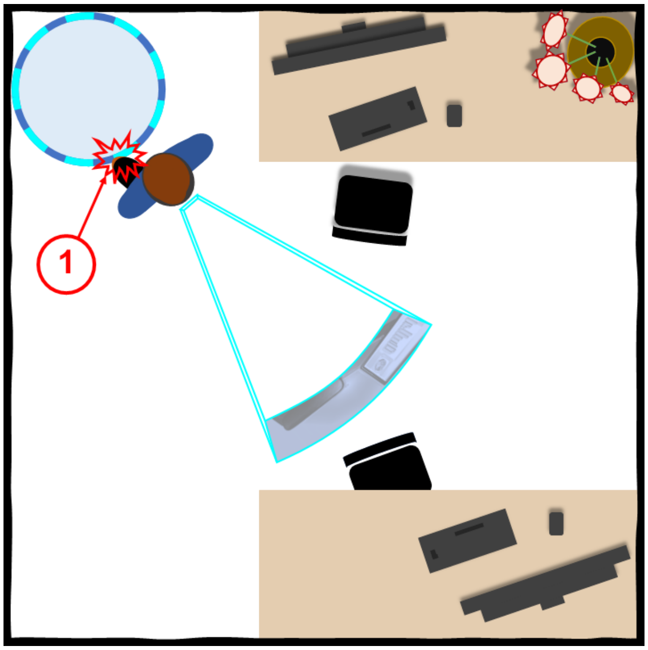


Figure 8: Stepping backwards into the portal while trying to see more of the mixed environment through the HMD.

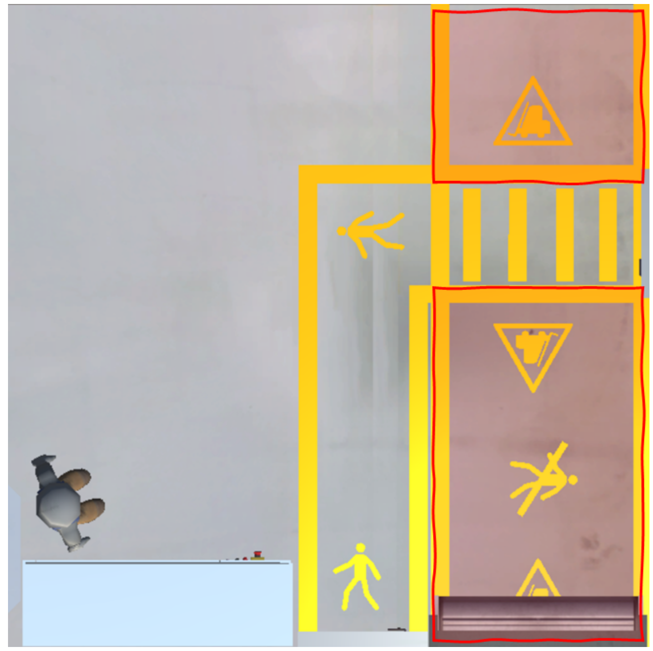


Figure 9: The alarm zone depicted as red rectangle for driving paths. Whenever a users steps into an alarm zone, an alarm sound is played.

the user looks at one video]" (DfM15, DfM19) which demonstrate how the implemented hand gestures are used to interact with virtual objects.

To eliminate the unintentional triggering of the portal, we decided to only activate it when users step into the portal while it is in the users' field of view (DfM06, DfM11, DfM14). Furthermore, we wanted to inform the users that new content is going to be loaded. We added a loading indicator, which also delays the change of virtual content by two seconds before showing the new scene (DfM07). This provides users with time to reflect on what happened and if needed stepping out of the portal again to interrupt. Using a virtual object, users have to step into, challenges the bodily integrity of the users [49], but in contrast to colliding with a chair or desk, the portal is designed to depict an abstract object. A shown in Figure 10, it is semi-translucent and shows dark blue bars moving from top to bottom. In contrast to encouraging users to enter an area, for the purpose of indicating the areas, where employees are not allowed to enter, we decided to play an alarm sound when the users' enter, which is played until they leave the respective area again (DfM08, DfM09, DfM16, DfM18, DfM20, Figure 9). We intentionally did not inform users of this mean of interaction with their body, since the requirement of not using text (DfM02) did not allow us to provide more complex instructions. It furthermore demonstrates a different kind of hazardous situation at the workplace: These restricted areas are part of the working environment by design, in contrast to many other hazardous situations, which are the result of human misconduct at the workplace (e.g., switching off safety devices). Therefore, identifying the potential thread is not related with taking action to remove the dangerous situation. Instead, employees are required to follow certain rules to avoid being injured. Yepes-Serna et al. [55] indicate that for learning applications, surprising application behaviour might lead to an increased cognitive load, which can influence the learning outcome. This highlights that designers should scarcely introduce unintentional interaction.

4.3.4 Pattern Statement. The broad complexity of how the human body interacts with the real-world is unlikely to be reconstructed in an MR application. Still, MR creators should consider different ways of including the users' positions, head movements, gestures, and maybe even postures into their interaction concept. This allows to introduce power entities, which users know from real-life to have an influence on their body while interacting with the environment and how they perceive their body, guiding them to perform according to the MR application's narrative. These power entities can be triggered as a reaction of intentional but also unintentional input. While a broad bandwidth on the one hand can depict important aspects from reality, users on the other hand can only benefit from those means when they are aware of them, or they become aware of them while using the application. These forces need to be mitigated by MR creators, who will have to make sure that the necessary means are introduced properly, either in a structured way (e.g., during a tutorial before use) or in a learning-by-doing fashion. The latter requires repeatable application behaviour to allow users applying trial and error to understand why the application is a reaction to their input. The tension manifests itself in the trade-off between the forces caused by the needs of simplicity and robustness of interaction modes.

P3: In applications with a three-dimensional spatial interface, such as MR applications, movement is a vital part of exploration and therefore must be encouraged by the system design. MR creators are charged with the task to select suitable interaction modes. Besides the set of inputs, provided by the MR system they target, the MR creators must consider introducing body-based input modes which encourage movement for extending the interaction possibilities within their mixed environment. Furthermore, MR creators have to define intentional and unintentional input and create suitable responses from the mixed environment and need to inform the users about how to control the system using suitable communication channels which address the users capabilities.

4.4 Wayfinding in Virtual and Real Spaces: Fostering the Cognitive Map

4.4.1 Problem. When we considered how users find their way through the mixed environment, two "forces" challenge it. On the one hand, we wanted to support users with familiar methods for navigation through mixed environments. On the other hand, we wanted to keep the space in a dedicated area, which requires sequentially overlapping the real environment with different virtual content. Both forces cannot be addressed comprehensively, so designers face ***the problem of balancing navigational clues without extending the mixed environment beyond the limited physical space***.

4.4.2 Context. Wayfinding, as presented in this pattern, and human approaches to cope with this challenge, have been characterised by Xu et al. [54]: When humans try to identify a possible path to move through an environment, they primarily rely on environmental factors, such as landmarks, and cognitive information, such as cognitive maps [53]. Humans also use this information to estimate distances [36]. Cognitive maps describe the users' internal spatial representation of an environment [19], or conceptual model of the reality they develop while exploring. Human wayfinding depends on fostering cognitive maps. Active wayfinding, like finding new routes but also repeating known routes, helps to develop these maps [20]. In the early designs, we planned to connect the single scenes of the mixed environment using doors. These doors were to be placed in the initial scene (lobby) and supposed to be used to enter the other scenes in random order (i.e., the order the user decides to apply). Two approaches to handle how these doors can be employed and their impact on cognitive map development during the use of the application, were discussed:

- Users could have to walk through a door, and therefore would need to step forward and expect to be in the next room on the other side of this door, which would increase the dimensions of the required area. Still, this solution partly supports human cognitive map development approaches, since there is a room behind the door in which users can step into, as expected. We identified that on a map, the rooms on the cognitive map would either intersect (Figure 11), or the rooms would have to be very narrow (Figure 12).
- Users could click on a door (leading to the room they intend to go to), which loads the specific content. Instead of stepping through the door, as it would be natural, they then would have to turn around to see the new virtual content in

Figure 10: The final design of the portal and an instructional poster next to it.

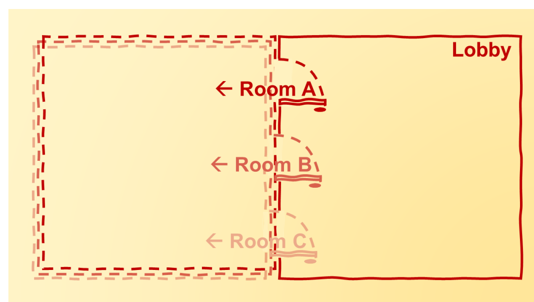


Figure 11: A potential cognitive map developed when, behind three doors placed on one wall, there would be rooms with the same wall size. The rooms would overlap on the cognitive map.

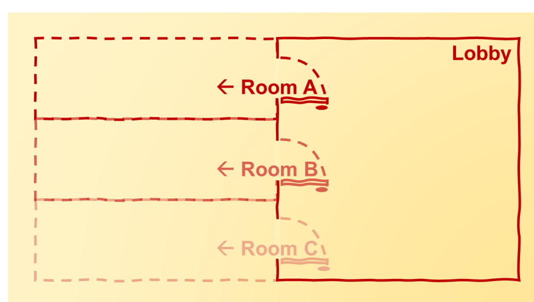


Figure 12: A potential cognitive map developed when behind three doors place don one wall, there would be rooms each with one third of the wall's length wide. The rooms would be stretched like a hallway.

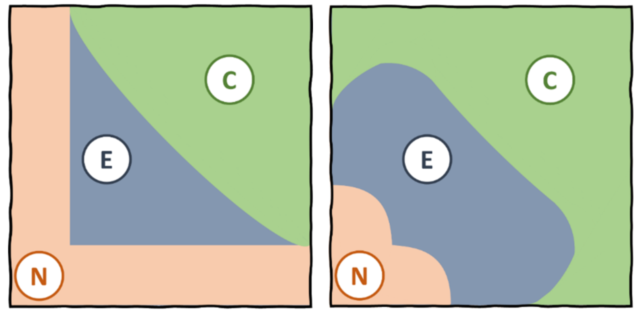
the same physical environment. This approach would not increase the required area, but would require the users to deviate from how they perform wayfinding by adjusting their cognitive map building approaches.

These two approaches either support wayfinding and cognitive map development, or they are economic in terms of required physical space. In both cases, similar to palimpsests, where author after author scraps off old layers of text from a parchment to reuse it, but cannot remove all traces, these overlaying environments leave traces in the cognitive maps, which can hinder interpreting it.

The location of the six doors for the six rooms was also of concern (WVR01, WVR03), since each door would have to be in the same location in both rooms (the lobby and the themed room). We were worried that if the doors weren't in consistent locations, users might feel "respawned" after new content loaded without the door back being in the expected location. While static setups can address this, our project goals included accommodating potential changes in room order, even after the application was in use, to meet customer requests (WVR02). Therefore, a fixed order cannot be guaranteed during the entire application life cycle. To allow iterating the MR application's content, a large area would have to be reserved for the potential location of the door. This area then would not be available to place the actual training content, as shown in Figure 13 (a).

4.4.3 Solution chosen in our project. After some consideration, we concluded that a horizontal floor plan (a map on just one level) is not a sufficient solution for our application's design. Instead, we use an elevator with which users can travel to different floors, resulting in a vertical floor plan (i.e., several rooms on several levels) (WVR04, WVR05, WVR06). People are used to the fact that when using an elevator, they (1) enter, (2) feel that they are moving and then (3) arrive somewhere else. Therefore, we concluded that it would support cognitive map building better than several doors. It furthermore allows using more space for the actual content (shown in Figure 13 (b)) without disrupting "natural" approaches of cognitive map building. Additionally, with the elevator in the same location in all rooms, changing the order of rooms, or even adding a new one is more feasible. MR creators just have to change the order of the buttons or add another one. The buttons are placed on the elevator's frame and therefore this approach gives MR creators more space for placing content.

4.4.4 Pattern Statement. When people navigate through their environment, they build up a cognitive map to be able to orientate in their environment. They therefore use a set of mechanisms for cognitive map building and will detect if there are discrepancies in their cognitive map. In MR applications, the cognitive map of the real world (created by walking through a room or building) is superimposed by a virtual map. Misleading information, or superposition of several rooms, which are illogical to the user may hinder this process and therefore prevent users from orienting themselves in the mixed environment. A large mixed environment can be based on a very small real environment, and one real environment can be superimposed by different virtual scenes. Therefore, MR creators should consider different ways of extending the mixed environment to not interrupt the process of wayfinding.



(a) *(b)*

Figure 13: Basic floor layouts. Ⓝ is the dedicated area to navigation between rooms, Ⓒ for interactive content on Occupational Health and Safety, and Ⓔ for the empty space in which users can move freely. In (a), space Ⓝ for six doors and in (b), Ⓝ for the elevator and a portal is planned.

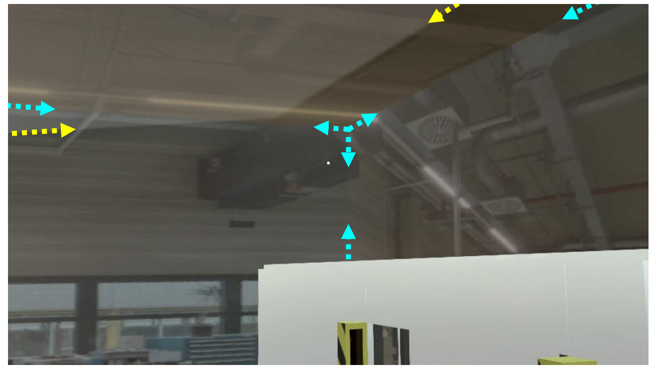
P4: Cognitive map development must be supported when designing MR applications. MR creators must employ means of navigation which are inspired by reality and suit to the MR application's basic layout. Furthermore, in MR, two or more different mixed environments can occur in the same real environment and MR creators have to mitigate the transition of the virtual content while the real content remains.

4.5 Design for the Unknown Environment: Control, Delegate, Let Go

4.5.1 Problem. There are three "forces" we were exposed to when it comes to making assumptions on the targeted environment: (1) working in a lab posed the risk to embracing a very narrow idea of the real environment, based on our testing space, for too long, (2) real spaces can set the tone for the user experience in a mixed environment, and (3) developers might not know much about the environments the final application will be used in. We encountered these forces to characterise ***the problem of designing for the unknown environment.***

4.5.2 Context. Much of the project's duration focused on resolving issues critical to the application's foundation. However, we stayed too long in lab testing, delaying the incorporation of real-world environment characteristics. When we finally tested our MR application outside the lab, we encountered issues in an auditorium with tall ceilings exceeding the tracking limit of five meters. Since up to then, we were never exceeding the tracking limit, our application required information on the ceiling's location to display the mixed environment accurately. We expected this to stabilise the tracking. Hence, we were not able to start the application (DUE01, DUE02, DUE03, DUE04, DUE05, DUE06). We also learned that the context in which the application is used in is important on several levels, not only that the real space meets the requirements of the application, but also that the impression of our application in a high room, in which we tested it later, was different from our usual

(a)



(b)

Figure 14: The MR application (edges highlighted with blue arrows) in two rooms of different ceiling heights. In (a), the room is about seven meters, and the real corner is visible through the virtual ceiling (yellow arrow). In (b), the real ceiling is about the same height as the virtual ceiling. The white ceiling suspension is clearly visible (yellow arrows).

test environment. In our testing environment, the real ceiling and the virtual ceiling were aligned (both were in about 2.5 meters). The ceiling was very present in this room (similar to Figure 14 (b)). In the high room, the virtual ceiling at the same distance was less oppressive, since there was some empty space behind it (similar to Figure 14 (a)). Also, the physical environment walls', floor's, and ceiling's colour changes the way the mixed environment appears.

During the application development, those team members with experience in manufacturing environments and the customer sketched the environment together. Aside, two members of the project also visited one of the customers plants to collect material for background pictures ("wallpapers") but also to get impressions of how the companies culture unfolds in departments producing, maintaining, constructing and administrating. These first impressions and experiences were collected and applied to the initial design of the MR application. In total, three people directly contributed in this phase which can be considered as a design-evolutionary bottleneck, while the rest of the project team was starting to implement the drafts.

4.5.3 Solution chosen in our project. After detecting that high rooms cannot be used, we adapted the application so tracking the ceiling was no longer required that the application starts loading content. Tracking two walls and floor also was sufficient to do a proper alignment of reality and virtual content (DUE07). We have also expanded our portfolio of test environments by including a room with a high ceiling (DUE03). To further balance the forces of the unknown environment, we included some instructions in the application's manual, on how to prepare the setting to guarantee stable use, such as using a room without too many windows, since they cannot be tracked by the used HMD. Since our application is located on the Augmented Virtuality side of the Virtuality-Reality Continuum (see [35]), the features of the real environment are still present. In contrast to many other MR applications, which are located on the Augmented Reality side, we provide wallpapers on all four walls (as shown in Figure 10) as well as the floor and the ceiling, which visually limit the mixed environment but more important this solution superimposes all features from reality with virtual content. This reduces the weight they have on the experience, which is depicted in Figure 14.

4.5.4 Pattern Statement. With MR, the real environment becomes a vital part of the MR experience. At minimum, it serves as a background, which is included into the experience and therefore needs to be interpreted by the MR application. The mix of the "two" environments also mixes experiences made in real-life and MR. When users, for example, perceive the real room as uncomfortable, this attribute will also be part of the experience in the MR which unfolds in the room. MR creators need to be aware of the environment's attributes to include them and mitigate between the virtual and the real content. Besides, MR creators have to be aware that there will be environments in which the use of the MR application fails, because they may not have foreseen a specific attribute of this environment.

P5: To properly design for the unknown environment, MR creators must analyse and extensively test in a portfolio of environments, which needs to be populated by characteristics of the targeted environments. The resulting requirements must be reflected in the MR application, such as for preventing certain environments from being used. Also, MR creators have to reduce the amount of characteristics of the physical environment, required for providing proper alignment of the virtual content, when possible.

5 DISCUSSION

This paper introduces Design Patterns for MR based on a structured reflection on the evolution of our design. We returned to its development and design process to reflect on our occupational health and safety training project in MR and collect traces of this design evolution. Since we applied a software engineering process to our project, we could use various sources to retrace the project. During the reflection exercise, we identified aspects of the Virtuality-Reality Clash that MR creators might need to consider.

Table 1: The patterns and identified related literature describing a similar pattern Ⓢ or aspects of it Ⓐ.

Pattern	Related Literature
P1 *Signifiers and Actual Affordances* advises to consciously deviate from the basic design language to highlight those signifiers which actually offer affordances.	"See the Unseen: …make visible the otherwise invisible" [10] Ⓢ, "Complexity can be lowered by a number of strategies such as using isolated elements." [52] Ⓐ
P2 *On Dimensions* advocates for being aware that users need to know what are the requirements on the real environment in order to mix it with a virtual one, but also that the size of an object partly makes how it will be perceived by people.	"Location- independent use: …it must support locations of various sizes and inform […] of the space requirements" [24] Ⓐ, "…respondents in the small environment [limited] the amount of intimate information and [answered] in more general terms…" [39] Ⓐ
P3 *Design for Movement* encourages designers to make use of body movements in MR applications but also sets out that providing bodily interaction needs to be done consciously.	-
P4 *Wayfinding in Virtual and Real Spaces* highlights the humans' need to navigate through their environment, and that mixing reality with virtuality can interfere with finding the way through the mixed environment.	"Drive by gamified story" [10] Ⓐ, "A higher level of wayfinding anxiety was reported by Americans, and women in both countries [USA and Hungary]…" [30] Ⓐ
P5 *Designing for the Unknown Environment* emphasizes the importance of understanding the prospect of the fact that designers can only partly control the user experience since the real environment, which is fused with designed virtual content to a mixed environment, can weigh heavy on the overall user experience	"Alignment of Physical and Virtual Worlds" [6] Ⓐ, "…distinct enough […] regardless of background." [8] Ⓐ, "…sufficient contrast between the overlay text and background." [15] Ⓐ, "User Safety: …Avoid placing key or primarily virtual experiences near […] places likely to result in an accident." [22] Ⓐ, "Contrast to background: A sufficient contrast between single elements […] and the real world…" [24] Ⓐ, "The good perceptibility of the information is the basic requirement for the recognition of contents." [25] Ⓐ, "Readability: […] particular attention should […] be paid to the readability of the text" (translated from German) [26] Ⓐ, "Allow different kinds of visual appearance attributes: […] The user should remain in control over the appearance…" [45] Ⓐ

To support MR creators based on our experience and reflection, we propose five Design Patterns to handle aspects of this clash. Structurally reflecting on our design evolution provided a better understanding of the impact of our design decisions, how they facilitated or hindered the project's progress, and anticipated future issues while using the software. The reflection exercise made us more conscious of designing practices we already applied in ad-hoc decisions to fulfil our work tasks.

5.1 Design Patterns that address the Virtuality-Reality Clash

We have decomposed the Virtuality-Reality Clash, as encountered in our process, into five themes, which build the basis of five suggested Design Patterns. Aspects of these patterns can be found in literature, an excerpt summarised in Table 1. In addition, for **P1**, we could identify a pattern by Dunleavy [10], which follows a similar theme (see Table 1).

By introducing challenges posed by each underlying design problem and by elaborating on specific solutions, we aimed to make each pattern relatable and therefore contributing to narrow down the nature of the Virtuality-Reality Clash. While we motivated the Design Patterns dominantly on the basis of our own findings in the structured reflection and clustered them under the concept of the Virtuality-Reality Clash, these patterns also been discussed in previous work (see Table 1). Using our patterns enabled us to find related phenomena in literature, we wish to conclude on:

Signifiers and Actual Affordances (**P1**) are reflected on by Sweller et al. [52], who state that MR creators need to work with false affordances to not cognitively overload the user with opportunities. Furthermore, MR creators cannot foresee every potential way an artefact might be used and therefore also will not be capable to include all potential functionalities users expect from a certain signifier. The deviation of objects to indicate affordances has been suggested in the form emphasising and de-emphasising by Rolim et al. [45]: On the one hand, MR creators could emphasize affordances (see weight label in Figure 2). On the other hand, they could de-emphasise objects with false affordances to let them fade in the background. A third option, the course of our project suggests, is using stylising objects to emphasise them, for example, by increasing their size (see label on the coffee maker in Figure 2). Finally, using basic approaches of Gestalt theory (see also [43]) might also be facilitated to emphasise (or de-emphasise) actual affordances. This pattern has been further addressed by scholars as "See the Unseen" [10], aiming to make visible the otherwise invisible signifiers or "Form communicates function" [13], which, among others, refers to using known metaphors (e.g., the proximity Gestalt principle [43]) to communicate actual affordances.

On Dimensions (**P2**) is amplified by current limits in technology, especially the reduced field of view HMD provide, which require users to move around more to compensate this technological shortcoming by cognitively merging single perspectives into a bigger picture. The resulting increased movements in the environment by users further emphasise the need for enough physical space. Reducing the use of the application to very few, large physical environments, conflicts with the recommendation to enable the use of many different environments proposed by Koch et al. [24] for accessible MR design. To facilitate this, they advise to also inform users about how to prepare these environments. Okken et al. [39] mention that the environment affects what and how much information people share. For specific topics, a more spacious environment allows people to be more open. Therefore, the environment users are placed in also influences, how socially distant they are [23]. Additionally, Nishihara and Okubo [37] indicate that the concept of personal space exists in virtual environments as well, which requires certain objects, virtual agents or other users to be at certain distances to not be perceived as violating the intimacy of closeness.

When it comes to *Design for Movement* (**P3**), there is a multitude of approaches to include the users' full body, dedicated body areas, and body behaviour as input device. Among others, Stevenson Won et al. [50] suggest detecting the users' body postures for addressing the individual level of engagement and Endsley et al. [13] propose to employ the position and pose of users to adapt the way content is presented, allowing interaction with the environment from different perspectives or even with different movements. According to Ogawa et al. [38], a representation of the users' body "close-to-reality" in VR reduces the users' tendency to walk through virtual objects. Since in MR, users see their own body, this can be expected here as well. Pedersen [42], points out that humans in MR are not just present but also act and think at the same time, that is they permanently negotiate "the self in relation to others and the physical world". Oppegaard [40] phrases this negotiation as constant interpretation and reinterpretation of environments. The way the environment is designed depicts a certain culture, which allows or inhibits individuals to express facets of their identity, and enables or prevents them to act.

While we are offering known means for *Wayfinding in Virtual and Real Spaces* (**P4**), we did not include actively drawing the users' attention to specific objects, as recommended by Rolim et al. [45], since the application is supposed to be used with a trainer on-site, who can guide users. MR creators might introduce navigational support to help users and aim to reduce cognitive load [56] to control stress levels. Stress is known to influence performance in wayfinding [33]. Also, according to Lawton and Kallai [30], MR creators should consider that people of different gender and different cultures have different approaches to wayfinding. Dunleavy [10] adds that an application's narrative has an important "impact on the quality of the experience". Purposeful means of navigation, which support cognitive map development, are part of the narrative. The author indicates that the collection and synthesis of information about the environment, users are located in, will support them to get an impression of how the individual rooms are connected. Each particular time people use an MR application, there is one, and only one real environment, but MR allows superimposing various virtual scenes corresponding with reality [32]. It is up to the MR creators how many virtual scenes are displayed in this one real environment and how users are supported to make sense of this palimpsest of overlaying virtual scenes.

Aspects of *Designing for the Unknown Environment* (**P5**) were described by scholars. For example, Herbst et al. [22], indicate that for using MR in the wild, the real environment poses certain risks (e.g., the flowing traffic), especially if users are focused on solving tasks in MR. As part of this pattern, one of the most often identified challenges by scholars [8, 15, 24–26] is to make sure that the virtual information is depicted in a way that users can still access necessary information from the physical environment while using the MR application. Studying and characterising the environment, the application will be used in, is a common suggestion to handle this challenge [11, 22, 26, 31, 34]. Börsting et al. [6] indicate that alignment of the real environment and virtual artefacts needs to be assured, along with providing stable relations between virtual and real artefacts. Controlling the unknown environment by the users has been suggested by Rolim et al. [45]. They state that MR applications should be adaptable in terms of visual appearance. While they focus on instructions, in general it might be helpful to let the user adapt the appearance of the virtual objects to make them match with the real environments they are projected to but also the users' expectations. In contrast to the authors' suggestion, it might also be used to allow users to intensify the impact of the virtual content, so it can "overwrite" previous experiences made in a certain real environment. Another approach to handle effects of the unknown environment might be to reduce the amount of real environment shining through by employing diminished reality [46], sometimes also considered as a subset of MR [2], to complete completely occlude unwanted objects from reality. If suitable, MR creators might even want to reconsider and turn to VR.

Many aspects of the Design Patterns we attribute to the Virtuality-Reality Clash can be found in literature (see Table 1). Still, except P1, we could not identify any other Design Pattern, which is already covered in its entirety by work of others. Nevertheless, as depicted in Table 1, aspects of the Design Patterns **P1**, **P2**, **P4**, and **P5** have been identified by scholars.

5.2 Design patterns as an interwoven concept

While we presented the five Design Patterns independently, they are interwoven by sharing aspects that support each other. Some aspects shared between the patterns are depicted in Figure 15. Since this collection is not exhaustive, we discuss a selection of shared aspects in this section:

The pattern *Design for the Unknown Environment* has a constitutive character for the Virtuality-Reality Clash. The uncertainty which the unknown environment provides is immanent to the Virtuality-Reality Clash. The origin of the four remaining Design Patterns can be retraced to be one genre of this uncertainty. According to Chen and Stanney [7], moving through an environment supports developing a cognitive map (intersection of *Wayfinding in Virtual and Real Space* and *Design for Movement*) of said environment by collecting new information of it. Hence, the way MR creators prepare the mixed environment directly influences the quality of the cognitive map we build. The right amount of space to move (intersection of *Design for Movement* and *On Dimensions*)

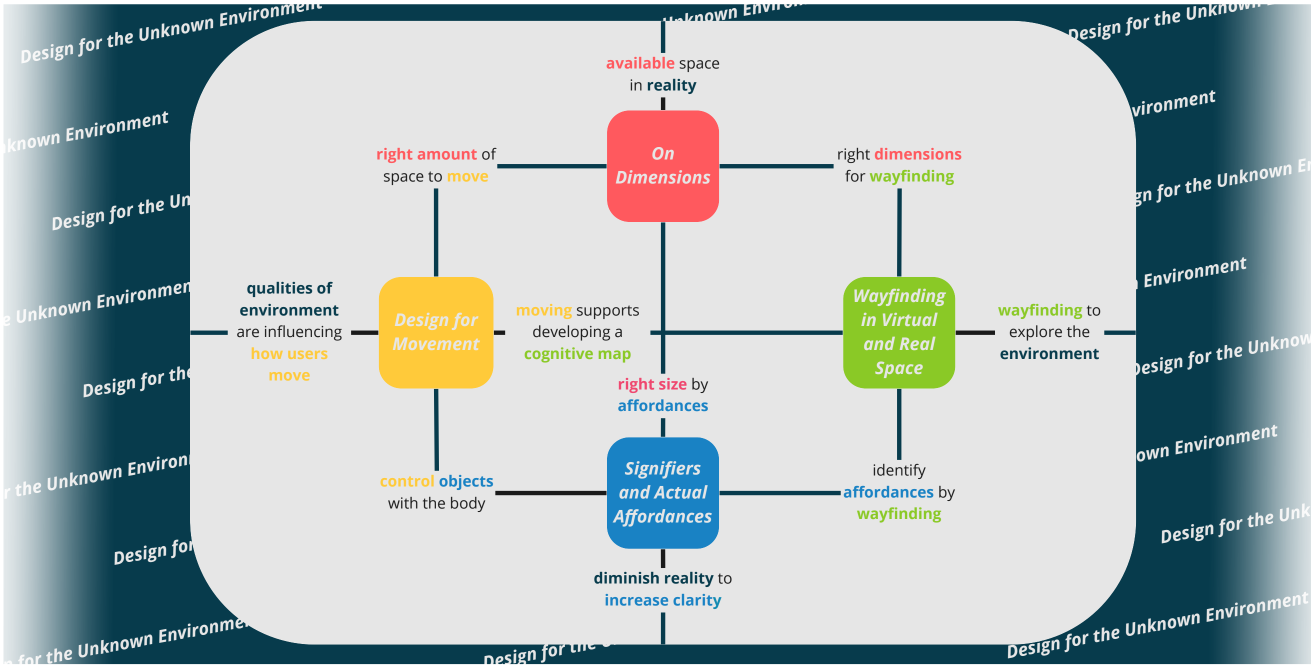


Figure 15: The five patterns and exemplary aspects they share with each other. *Design for the Unknown Environment* (grey frame) is a pattern for constitutive character for the Virtuality-Reality Clash, since aspects of it are also covered by the other four patterns.

prevents users from performing dangerous movements [24]. In contrast, again, too much space might have a negative influence on the way users are willing to employ their body for interaction with the mixed environment (see [23, 37]). The right dimensions also support that users perceive one continuous mixed environment, in which individual situations and their affordances can arise from a complex interplay between several objects (real and/or virtual). As mentioned by Geuss et al. [18], humans are capable of deriving the right size of objects by affordances they provide (intersection of *Signifiers and Actual Affordances* and *On Dimensions*). Hence, if objects afford certain functions, users can collect cues about the size of the objects and their environment and combine it with previous knowledge. For this reason, also providing the right dimensions for wayfinding (intersection of *Wayfinding in Virtual and Real Space* and *On Dimensions*) is crucial, since estimating distances to or sizes of objects in an environment is employed by humans to navigate.

5.3 Implications for Mixed Reality Developers and Designers

Based on the experience of applying our approach of structured reflection, we encourage fellow engineers to conduct similar approaches to structured reflection on the evolution of their design. By conducting this exercise, we could reconstruct our design decisions and trace their impact on the design. Working with the structured data body sometimes even served as a trigger for reviving emotions and work atmosphere, we experienced while developing and consequently designing the MR training application. This had an impact on retrospectively understanding team dynamics as well, because it uncovered the individual's contribution to the project in detail. Therefore, we also want to encourage design professionals to introduce more rigid documentation approaches into the conscious design process, since it could empower design folk to take a new historical perspective on their design approaches and further foster their conscious design process as an individual but also as a team.

Using documentation systems and developed software development also poses the risk of linearly streamlining design approaches. It requires an in-depth analysis of these tools to apply them to design activities consciously. Collecting, unifying, and structuring project documentation data from this project took, in our case, about five person months. This time to invest should be considered when deciding to perform structured reflection. Nevertheless, we understand this approach not just to share insights with others, but also as a chance to become more reflective on the design decisions made by someone who creates MR applications. Therefore, it could be interesting for researchers who design to do similar exercises occasionally. We understand the continuous and extensive documentation of development and design undertakings as key to our approach to structured reflection. For collecting traces, the visual reconstruction of the evolution of our design crystallized to be the driving aspect of the data corpus. It helped to reflect on decisions, enrich the data corpus by personal retrospection, and structure the revisiting of the remaining data corpus. To present our findings, we identified Design Patterns, close to the original definition by Alexander et al. [1] as suitable. They allowed us to generalize various data points into one design problem and present our undertakings to encounter specific characteristics of the Virtuality-Reality Clash close to our design practice. Finally, this approach highlighted what might make the Virtuality-Reality Clash a design phenomenon for MR designers. It depends on the extent of the project, but also the theoretical stance of the involved design reflectioneers and the research programs [29] or paradigms [28] in which they place their work, whether Design Patterns are the most suitable tool to present the results of such a structured reflection. After all, some alternatives may be more desirable under different conditions.

5.4 Limitations and Outlook on our Design Patterns

The presented Design Patterns are deducted from the analysis of a project in which an MR occupational health and safety training was created for and with a partner from the industry. This industrial application area depicts a distinct context which informed our Design Patterns. Transferring the Design Patterns to other application areas requires careful reflection on each pattern and potentially adapting them to factors such as the new field's regulations, cultural expectations, or technology acceptance levels.

We found aspects of four of our Design Patterns (**P1**, **P2**, **P4**, and **P5**) in literature for various application areas (e.g., for outdoor MR gaming [22], or MR educational applications [10]), which indicates that the industrial application area shares challenges of similar characteristics with other application areas. The Design Pattern **P3** invites to carefully trade-off encouraging body movements and exposing the users to others by requiring movements, which may be perceived to be improper by the users. Since MR creators are tasked with deciding on the modes of interaction, including body movements, we expect this Design Pattern to also be transferable to other application areas. Hence, these Design Patterns can and should be transferred into other application areas for two reasons: (1) critical design decisions can be informed by these patterns and (2) the multifaceted shape of each pattern can be worked out by applying them over and over again. MR creators might want to reflect on adapting these Design Patterns in other application areas by performing a structured reflection similar to the method applied in this work. Moreover, the presented Design Patterns are neither intended to be complete nor should they be seen as irrevocable rules MR creators must follow. Instead, we invite scholars to structurally reflect on finished MR projects, among others, in the light of the Virtuality-Reality Clash and refine, oppose, and extend these Design Patterns not just in industry.

While we focus on unwanted effects which characterise the Virtuality-Reality Clash, it also should be intentionally maintained in the background by MR creators to make the users aware that they are in a (partly) simulated environment to some extent. The absence of the Virtuality-Reality Clash, which could also be framed as Matrix[2]-like VR [48], might not be achievable, and it also might not be something MR creators should strive for. Creating a Virtuality-Reality Clash-free application would require to control every aspect of the users' environment, which, besides the general feasibility, raises a myriad of ethical questions, among others discussed by Slater et al. [49]. Analogues to the Matrix films, the absence of the Virtuality-Reality Clash, among others, facilitates the possibility to control people's opinions or the degree users are (not) in power of what happens to them in a simulated environment. Therefore, MR creators should be aware of this phenomenon and have approaches to address it, but also utilise it with care. In the end, designing the Virtuality-Reality Clash out poses the risk of being the source of Deceptive Patterns (see [5]), which are designed for tricking users to do things they did not decide on in various ways.

In future work, we aim to apply our Design Patterns to more MR projects for collecting further proof of its applicability. The Design Patterns we present, are mostly created with a focus on visual aspects, but perception is multifold. For example, using haptic interfaces or better incorporation of objects found in the context of use, as suggested by Li et al. [31] further challenge MR creators. They need to employ suitable, also non-visual, signifiers to indicate the underlying function, provide a sound matching between the stimuli, and make sure that the needed object is available in the environment. To establish these Design Patterns in everyday design practice, it might be of interest to foster material catalogues which provide MR objects for defined use cases, such as proposed by Risseeuw et al. [44]. Such catalogues could incorporate material which is based on approaches to address the Virtuality-Reality Clash and therefore bring the five Design Patterns, introduced in this paper, into application.

6 CONCLUSION

In this paper, we proposed an approach to revisit projects after they have been finalised to structurally reflect on design decisions. By exemplifying this approach, we identified five design problems based on the data collected from the MR creators' side, characterised by challenges, we refer to as Virtuality-Reality Clash and which occur when mixing reality and virtual artefacts to create MR applications. We present five Design Patterns which are based on these design problems. The purpose of these patterns is to sensitise MR creators to the Virtuality-Reality Clash and help them to handle related effects. Also, the patterns are used to characterise aspects of said Clash. Finally, we understand these design patterns to propose an interpretation of situations, in which design plays a major role, and recommend solutions in line with an individual design language. Learning for our structured reflection on the evolution of our application design, we hope to inspire fellow developers and designers to conduct similar exercises to become more conscious of the impact design problems and our mindset we show when making decisions to address these problems can have.

REFERENCES

[1] Christopher Alexander, Sara Ishikawa, and Murray Silverstein. 1977. *A Pattern Language: Towns, Buildings, Construction* (illustrated edition ed.). Oxford University Press, New York.

[2] Ronald Azuma, Yohan Baillot, Reinhold Behringer, Steven K. Feiner, Simon Julier, and Blair MacIntyre. 2001. Recent advances in augmented reality. *IEEE Computer Graphics and Applications* 21, 6 (Nov. 2001), 34–47. https://doi.org/10.1109/38.963459 Conference Name: IEEE Computer Graphics and Applications.

[3] Evren Bozgeyikli, Andrew Raij, Srinivas Katkoori, and Rajiv Dubey. 2016. Point & Teleport Locomotion Technique for Virtual Reality. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. Association for Computing Machinery, New York, NY, USA, 205–216. https://doi.org/10.1145/2967934.2968105

[4] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (Dec. 2006), 77–101. https://doi.org/10.

[2]science fiction film from 1999, where humans are "plugged in" and all sensory perceptions are overwritten by a computer system.

1191/1478088706qp063oa Publisher: Taylor & Francis (Routledge).
[5] Harry Brignull. 2023. *Deceptive Patterns: Exposing the Tricks Tech Companies Use to Control You.* Testimonium Ltd.
[6] Ingo Börsting, Can Karabulut, Bastian Fischer, and Volker Gruhn. 2022. Design Patterns for Mobile Augmented Reality User Interfaces—An Incremental Review. *Information* 13, 4 (April 2022), 159. https://doi.org/10.3390/info13040159
[7] Jui Lin Chen and Kay M. Stanney. 1999. A Theoretical Model of Wayfinding in Virtual Environments: Proposed Strategies for Navigational Aiding. *Presence: Teleoperators and Virtual Environments* 8, 6 (Dec. 1999), 671–685. https://doi.org/10.1162/105474699566558
[8] Oluwadunsin Dabor, Edward Longford, and Stuart Walker. 2019. Design Guidelines for Augmented Reality User Interface: A Case Study of Simultaneous Interpretation. In *2019 11th Computer Science and Electronic Engineering (CEEC).* 164–166. https://doi.org/10.1109/CEEC47804.2019.8974331
[9] Marco de Sá and Elizabeth Churchill. 2012. Mobile augmented reality: exploring design and prototyping techniques. In *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services (MobileHCI '12).* Association for Computing Machinery, New York, NY, USA, 221–230. https://doi.org/10.1145/2371574.2371608
[10] Matt Dunleavy. 2014. Design Principles for Augmented Reality Learning. *TechTrends* 58, 1 (Jan. 2014), 28–34. https://doi.org/10.1007/s11528-013-0717-2
[11] Daniel Eckertz, Jan Berssenbrügge, Harald Anacker, and Roman Dumitrescu. 2020. Work-in-Progress: Enhancing Collaboration Using Augmented Reality Design Reviews for Product Validation on the Example of Additive Manufacturing. In *Cyber-physical Systems and Digital Twins (Lecture Notes in Networks and Systems)*, Michael E. Auer and Kalyan Ram B. (Eds.). Springer International Publishing, Cham, 244–254. https://doi.org/10.1007/978-3-030-23162-0_22
[12] Felix Emmerich, Roland Klemke, and Thomas Hummes. 2017. Design Patterns for Augmented Reality Learning Games. In *Games and Learning Alliance (Lecture Notes in Computer Science)*, João Dias, Pedro A. Santos, and Remco C. Veltkamp (Eds.). Springer International Publishing, Cham, 161–172. https://doi.org/10.1007/978-3-319-71940-5_15
[13] Tristan C. Endsley, Kelly A. Sprehn, Ryan M. Brill, Kimberly J. Ryan, Emily C. Vincent, and James M. Martin. 2017. Augmented Reality Design Heuristics: Designing for Dynamic Interactions. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 61, 1 (Sept. 2017), 2100–2104. https://doi.org/10.1177/1541931213602007
[14] Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. 1994. *Design Patterns: Elements of Reusable Object-Oriented Software* (1 ed.). Addison-Wesley Professional.
[15] Subhashini Ganapathy. 2013. Design Guidelines for Mobile Augmented Reality: User Experience. In *Human Factors in Augmented Reality Environments*, Weidong Huang, Leila Alem, and Mark A. Livingston (Eds.). Springer, New York, NY, 165–180. https://doi.org/10.1007/978-1-4614-4205-9_7
[16] Bill Gaver and John Bowers. 2012. Annotated Portfolios. *interactions* 19, 4 (July 2012), 40–49. https://doi.org/10.1145/2212877.2212889
[17] Nirit Gavish, Teresa Gutierrez, Sabine Webel, Jorge Rodriguez, and Franco Tecchia. 2011. Design Guidelines for the Development of Virtual Reality and Augmented Reality Training Systems for Maintenance and Assembly Tasks. *BIO Web of Conferences* 1 (2011), 00029. https://doi.org/10.1051/bioconf/20110100029 Publisher: EDP Sciences.
[18] Michael Geuss, Jeanine Stefanucci, Sarah Creem-Regehr, and William B. Thompson. 2010. Can I pass? using affordances to measure perceived size in virtual environments. In *Proceedings of the 7th Symposium on Applied Perception in Graphics and Visualization (APGV '10).* Association for Computing Machinery, New York, NY, USA, 61–64. https://doi.org/10.1145/1836248.1836259
[19] Reginald G. Golledge. 1999. *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes.* JHU Press.
[20] Reginald G. Golledge, R. Daniel Jacobson, Robert Kitchin, and Mark Blades. 2000. Cognitive Maps, Spatial Abilities, and Human Wayfinding. *Geographical review of Japan, Series B.* 73, 2 (2000), 93–104. https://doi.org/10.4157/grj1984b.73.93
[21] Daniel Görlich, Tayfun Akincir, and Gerrit Meixner. 2022. An Overview of User Interface and Interaction Design Patterns for VR, AR, and MR Applications. Mensch und Computer 2022 - Workshopband. (2022). https://doi.org/10.18420/muc2022-mci-ws06-419
[22] Iris Herbst, Anne-Kathrin Braun, Rod McCall, and Wolfgang Broll. 2008. TimeWarp: interactive time travel with a mobile mixed reality game. In *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services (MobileHCI '08).* Association for Computing Machinery, New York, NY, USA, 235–244. https://doi.org/10.1145/1409240.1409266
[23] Tina Iachini, Yann Coello, Francesca Frassinetti, and Gennaro Ruggiero. 2014. Body Space in Social Interactions: A Comparison of Reaching and Comfort Distance in Immersive Virtual Reality. *PLOS ONE* 9, 11 (Nov. 2014), e111511. https://doi.org/10.1371/journal.pone.0111511
[24] Sebastian Koch, Tobias Ableitner, and Gottfried Zimmermann. 2022. Comparison of Guidelines for the Accessible Design of Augmented Reality Applications. In *Computers Helping People with Special Needs (Lecture Notes in Computer Science)*, Klaus Miesenberger, Georgios Kouroupetroglou, Katerina Mavrou, Roberto Manduchi, Mario Covarrubias Rodriguez, and Petr Penáz (Eds.). Springer International Publishing, Cham, 89–98. https://doi.org/10.1007/978-3-031-08645-8_11
[25] Regina Koreng and Heidi Krömker. 2019. Augmented Reality Interface: Guidelines for the Design of Contrast Ratios. In *Proceedings of the ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.* American Society of Mechanical Engineers Digital Collection, Anaheim, California, USA, 1–9. https://doi.org/10.1115/DETC2019-97341
[26] Sarah-Sabrina Kortekamp, Ingmar Ickerott, and Frank Teuteberg. 2021. Gestaltungsempfehlungen für Augmented-Reality- Applikationen – Ein Anwendungsbeispiel im Gesundheitswesen. (July 2021). https://library.gito.de/2021/07/wi2020-zentrale-tracks-45/
[27] Panos E. Kourouthanassis, Costas Boletsis, and George Lekakos. 2015. Demystifying the design of mobile augmented reality applications. *Multimedia Tools and Applications* 74, 3 (Feb. 2015), 1045–1066. https://doi.org/10.1007/s11042-013-1710-7
[28] Thomas S. Kuhn and Ian Hacking. 2012. *The Structure of Scientific Revolutions: 50th Anniversary Edition* (anniversary edition ed.). University of Chicago Press, Chicago.
[29] Imre Lakatos. 1978. *The Methodology of Scientific Research Programmes: Philosophical Papers.* Vol. 1. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511621123
[30] Carol A. Lawton and Janos Kallai. 2002. Gender Differences in Wayfinding Strategies and Anxiety About Wayfinding: A Cross-Cultural Comparison. *Sex Roles* 47, 9 (Nov. 2002), 389–401. https://doi.org/10.1023/A:1021668724970
[31] Jingya Li, Erik Van Der Spek, Jun Hu, and Loe Feijs. 2022. Extracting Design Guidelines for Augmented Reality Serious Games for Children. *IEEE Access* 10 (2022), 66660–66671. https://doi.org/10.1109/ACCESS.2022.3184775
[32] Sha Liang. 2016. Design principles of augmented reality focusing on the ageing population. In *Proceedings of the 30th International BCS Human Computer Interaction Conference: Fusion! (HCI '16).* BCS Learning & Development Ltd., Swindon, GBR, 1–7. https://doi.org/10.14236/ewic/HCI2016.2
[33] Jing Lin, Lijun Cao, and Nan Li. 2019. Assessing the influence of repeated exposures and mental stress on human wayfinding performance in indoor environments using virtual reality technology. *Advanced Engineering Informatics* 39 (Jan. 2019), 53–61. https://doi.org/10.1016/j.aei.2018.11.007
[34] Rod McCall, Iris Herbst, Anne-Kathrin Braun, and Richard Wetzel. 2008. The "where" of mixed reality: some guidelines for design. Florence, Italy. https://eprints.lincoln.ac.uk/id/eprint/24609/
[35] Paul Milgram and Fumio Kishino. 1994. A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems* E77-D, 12 (1994).
[36] Jack L. Nasar. 1983. Environmental Factors, Perceived Distance and Spatial Behavior. *Environment and Planning B: Planning and Design* 10, 3 (Sept. 1983), 275–281. https://doi.org/10.1068/b100275
[37] Ryota Nishihara and Masashi Okubo. 2015. A Study on Personal Space in Virtual Space based on Personality. *Procedia Manufacturing* 3 (Jan. 2015), 2183–2190. https://doi.org/10.1016/j.promfg.2015.07.359
[38] Nami Ogawa, Takuji Narumi, Hideaki Kuzuoka, and Michitaka Hirose. 2020. Do You Feel Like Passing Through Walls?: Effect of Self-Avatar Appearance on Facilitating Realistic Behavior in Virtual Environments. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20).* Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376562
[39] Vanessa Okken, Thomas van Rompay, and Ad Pruyn. 2013. Room to Move: On Spatial Constraints and Self-Disclosure During Intimate Conversations. *Environment and Behavior* 45, 6 (Aug. 2013), 737–760. https://doi.org/10.1177/0013916512444780
[40] Brett Oppegaard. 2017. Designing, Arranging, and Assessing Augmented Places through Mobile Media Alignment. 26–44.
[41] Hannah Park, Nafiseh Faghihi, Manish Dixit, Jyotsna Vaid, and Ann McNamara. 2021. Judgments of Object Size and Distance across Different Virtual Reality Environments: A Preliminary Study. *Applied Sciences* 11, 23 (Jan. 2021), 11510. https://doi.org/10.3390/app112311510
[42] Isabel Pedersen. 2009. Radiating centers: Augmented reality and human-centric design. In *2009 IEEE International Symposium on Mixed and Augmented Reality - Arts, Media and Humanities.* 11–16. https://doi.org/10.1109/ISMAR-AMH.2009.5336735 ISSN: 2381-8360.
[43] Peng Peng, Kai-Fu Yang, and Yong-Jie Li. 2021. A computational model for gestalt proximity principle on dot patterns and beyond. *Journal of Vision* 21, 5 (May 2021), 23. https://doi.org/10.1167/jov.21.5.23
[44] Martin Risseeuw, Dario Cavada, Elena Not, Massimo Zancanaro, Mark T. Marshall, Daniela Petrelli, and Thomas Kubitza. 2016. Authoring Augmented Digital Experiences in Museums. In *Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '16).* Association for Computing Machinery, New York, NY, USA, 340–341. https://doi.org/10.1145/2909132.2926064
[45] Cledja Rolim, Dieter Schmalstieg, Denis Kalkofen, and Veronica Teichrieb. 2015. [POSTER] Design Guidelines for Generating Augmented Reality Instructions. In *2015 IEEE International Symposium on Mixed and Augmented Reality.* 120–123. https://doi.org/10.1109/ISMAR.2015.36

[46] Cledja Rolim and Veronica Teichrieb. 2012. A Viewpoint about Diminished Reality: Is it Possible Remove Objects in Real Time from Scenes?. In *2012 14th Symposium on Virtual and Augmented Reality*. 141–146. https://doi.org/10.1109/SVR.2012.6

[47] Taana Rose, Eve Klein, and Frederico Fialho Leandro Alves Teixeira. 2023. Self-Experiential Prototyping for Augmented and Virtual Reality Opera Creation. *Chroma: Journal of the Australasian Computer Music Association* 39, 1 (May 2023). https://journal.computermusic.org.au/chroma/article/view/10 Number: 1.

[48] Richard Skarbez, Missie Smith, and Mary C. Whitton. 2021. Revisiting Milgram and Kishino's Reality-Virtuality Continuum. *Frontiers in Virtual Reality* 2 (2021). https://doi.org/10.3389/frvir.2021.647997

[49] Mel Slater, Cristina Gonzalez-Liencres, Patrick Haggard, Charlotte Vinkers, Rebecca Gregory-Clarke, Steve Jelley, Zillah Watson, Graham Breen, Raz Schwarz, William Steptoe, Dalila Szostak, Shivashankar Halan, Deborah Fox, and Jeremy Silver. 2020. The Ethics of Realism in Virtual and Augmented Reality. *Frontiers in Virtual Reality* 1 (2020). https://doi.org/10.3389/frvir.2020.00001

[50] Andrea Stevenson Won, Jeremy N. Bailenson, and Joris H. Janssen. 2014. Automatic Detection of Nonverbal Behavior Predicts Learning in Dyadic Interactions. *IEEE Transactions on Affective Computing* 5, 2 (April 2014), 112–125. https://doi.org/10.1109/TAFFC.2014.2329304

[51] Jaclynn V. Sullivan. 2018. Learning and Embodied Cognition: A Review and Proposal. *Psychology Learning & Teaching* 17, 2 (2018), 128–143. https://doi.org/10.1177/1475725717752550

[52] John Sweller, Paul Ayres, and Slava Kalyuga. 2011. Altering Element Interactivity and Intrinsic Cognitive load. In *Cognitive Load Theory*. Springer New York, New York, NY, 203–218. https://doi.org/10.1007/978-1-4419-8126-4

[53] Elisângela Vilar, Francisco Rebelo, and Paulo Noriega. 2014. Indoor Human Wayfinding Performance Using Vertical and Horizontal Signage in Virtual Reality. *Human Factors and Ergonomics in Manufacturing & Service Industries* 24, 6 (2014), 601–615. https://doi.org/10.1002/hfm.20503

[54] Yan Xu, Evan Barba, Iulian Radu, Maribeth Gandy, Richard Shemaka, Brian Schrank, Blair MacIntyre, and Tony Tseng. 2011. Pre-patterns for designing embodied interactions in handheld augmented reality games. In *2011 IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities*. 19–28. https://doi.org/10.1109/ISMAR-AMH.2011.6093652 ISSN: 2381-8360.

[55] Vanesa Yepes-Serna, Mario Wolf, Heinrich Söbke, and Steffi Zander. 2021. Design Principles for Educational Mixed Reality?: Adaptions of the Design Recommendations of Multimedia Learning. In *Advances in Educational Technologies and Instructional Design*, Gokce Akcayir and Carrie Demmans Epp (Eds.). IGI Global, Hershey, PA, USA, 76–99. https://doi.org/10.4018/978-1-7998-5043-4.ch004

[56] Jinyue Zhang, Xiaolu Xia, Ruiqi Liu, and Nan Li. 2021. Enhancing human indoor cognitive map development and wayfinding performance with immersive augmented reality-based navigation systems. *Advanced Engineering Informatics* 50 (Oct. 2021), 101432. https://doi.org/10.1016/j.aei.2021.101432

APPENDIX

Table 2: Data points used to inspire *Signifiers and Actual Affordances.*

Ref	Identifier	Date	Content
SaA01	git commit 79164cd6	29/08	missing label
SaA02	Meeting 0910	09/10	"25 kg" label on box
SaA03	Jira ticket ARS-109	15/11	Office02: Labelling box "25 kg"
SaA04	Meeting 1511	15/11	Labelling cardboard box"25 kg"
SaA05	Jira ticket ARS-127	15/11	Assembly01: Light barrier equipped with label, key switch directly on light barrier (and larger)
SaA06	git commit ab9f8cd7	23/11	Added text on green box
SaA07	Meeting 1412	14/12	Turn the coffee machine slightly (so that the label is more visible)
SaA08	git commit a04c8f39	17/12	Rotated Coffee Machine in Office02

Table 3: Data points used to inspire the Virtuality-Reality Clash-Design Pattern *On Dimensions.*

Ref	Identifier	Date	Content
ODs01	comment on ARS-28	27/06	fixed cube 5×5×2.5
ODs02	git commit 2a44c2f3	17/07	some merge outliers [collection of data, which caused merged errors]
ODs03	git commit cfaf2ab	27/07	re-scale objects
ODs04	Meeting 0108	01/08	The working area is a bit small, which makes the scene look crowded. We enlarge the area to max. 5×5 m, initially we test 4×4 and increase step by step if necessary
ODs05	Mail 1808a	18/08	We had [smaller objects] in between times, unintentionally. The entire interior looked like a doll's house, and you ended up standing very high above it and looking at it from above. You had the feeling you could peek over the door into the room.
ODs06	Jira ticket ARS-119	15/11	Manufacturing03: move virtual agent (compressed air) more into the corner
ODs07	Jira ticket ARS-105	15/11	Portal closer to the walls (as far away from scene as possible)

Table 4: Data points used to inspire *Design for the Unknown Environment.*

Ref	Identifier	Date	Content
DUE01	Jira ticket ARS-4	07/05	get room coordinates
DUE02	Meeting 1809	18/09	…Unfortunately, we had technical problems when preparing the demo on site, so we couldn't display the rooms at all. Shortly before, everything worked perfectly in the lab. We are currently looking into this…
DUE03	Mail 1909a	19/09	…In the meantime, we have also found the error and partially corrected it. Due to the high room height, the ceiling was not covered, but this was absolutely necessary until our change. We tested it in our auditorium. The HoloLens cannot detect the ceiling there either…
DUE04	git commit 17d84994	19/09	…changed the default value for ceiling
DUE05	Jira ticket ARS-56	21/09	Room Scanning not Working in Big rooms: Based on the current logic the application doesn't allow to scan properly the corner in a big room.
DUE06	Jira ticket ARS-57	21/09	Change minimum required walls and required ceiling
DUE07	git commit 8895e973	24/09	removed ceiling condition

Table 5: Data points used to inspire the Virtuality-Reality Clash-Design Pattern *Design for Movement*.

Ref	Identifier	Date	Content
DfM01	Requirement01a	-	user moves around in it -> Important: User is supposed to move around! Consciously doing something actively
DfM02	Meeting 2506	25/06	...avoiding the issue of language.
DfM03	Jira ticket ARS-35	03/07	Implement Portal
DfM04	Meeting 1707	17/07	Portal must be intentionally activated and deactivated. Unintentional entry must not lead to the scene being changed.
DfM05	Jira ticket ARS-47	31/07	Place Portal correctly
DfM06	Jira ticket ARS-48	31/07	Portal on/off concept
DfM07	git commit 42aad69f	08/10	Initial implementation portal scene loading indicator
DfM08	Jira ticket ARS-81	10/10	Manufacturing 3: ... after moving blocking palette check if user is in driving path (honk if yes)...
DfM09	Jira ticket ARS-84	11/10	Modify Manufacturing02
DfM10	Jira ticket ARS-85	12/10	Teleporter Logic
DfM11	Jira ticket ARS-106	15/11	Running backwards into the portal does not change the scene
DfM12	Jira ticket ARS-132	15/11	Maintenance02: barrier not respected -> alarm (audio and image)
DfM13	Jira ticket ARS-139	15/11	Instructions must explain how to use elevator and portal (incl. advice to take hands out of field of view if no interaction)
DfM14	git commit 7dab21b7	10/12	Portal changed scene only when user walks in while looking at portal
DfM15	git commit bf3df9ae	11/12	added instructional whiteboards and videos to Lobby videos play on gaze using the OnGaze-CursorPlay script
DfM16	git commit 8b8b4554	14/12	Added Alarm in restricted area
DfM17	git commit 8b8b4554	14/12	... Added portal instructions in SceneManager scene
DfM18	git commit a04c8f39	17/12	added alarm collider to Assembly02 adjusted AlertsManager to play different sound (looping missing)
DfM19	git commit 93c079e0	14/01	... Changed PlayVideoOnGazeCursor script in Lobby...
DfM20	git commit d1d46949	18/01	Looping alert sounds

Table 6: Data points used to inspire the Virtuality-Reality Clash-Design Pattern *Wayfinding in Virtual and Real Space*.

Ref	Identifier	Date	Content
WVR01	requirement02c	-	Training has basis module with 5-6 "Safety rooms": ... Lobby with 5-6 doors (to the safety rooms)...
WVR02	Meeting 2704	27/04	Lobby needs to be extendable
WVR03	Meeting 1506	15/06	lobby with 6 doors (different colours and materials)
WVR04	Jira ticket ARS-30	27/06	design lobby: ... Elevator...
WVR05	Comment on ARS-30	17/08	We will use an elevator now, Symbols for the different "level" are placed next to elevator as a dashboard, The Lobby-Symbol will be highlighted as we stand in the lobby...
WVR06	git commit b6d48805	23/10	Added Elevator in SceneManager Scene