SwageXR: Designing Gamified AR Applications for Industrial Training

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Abstract: This paper presents a case study describing the design of SwageXR, an augmented reality (AR) application that gamifies a tubing assembly exercise. The aim of this paper is to contribute to the field of extended reality (XR) applications by providing a case study of a novel design process based on an existing framework by Gilardi et al.

Design needs and requirements were gathered using a contextual design approach and qualitative research through interviews with training course instructors as well as a workshop involving them. The contextual design approach involved the PI taking part in the training course as one of the trainees to observe and build understanding of the taught practical content and the context in which the learning happened. This was followed by semi-structured interviews with 4 training instructors, with results indicating preferred course content to digitise, early concepts for gamification, and the storyline of the gamified content with respect to existing training. Using the data and experience gained from the contextual design approach and interviews, a paper prototype of the gamified AR application was developed, and feedback was obtained from the company technical director. The paper prototype and feedback were used as a basis for developing a 3D prototype in VR using ShapesXR. This led to a virtual reality (VR) workshop involving the technical director and training manager of the company where the 3D prototype was demonstrated and discussed. The workshop resulted in the flow of the overall application being refined including the storyline, gamification, training, and challenges. The design process aims to facilitate the development of a coded working prototype for SwageXR, with gamification elements such as score, time-based challenges and leaderboards. An initial experience playtest with course trainees will then be possible to gain insight on engagement levels and trainee attitudes about the initial game experience.

The main outcome of this research is a design approach that tries to address the gap outlined by Krauß et al., the approach makes use of rehearsal techniques and virtual reality to provide context for AR application design.

Keywords: Extended Realities, Augmented Reality, Design Process, Industrial Training, Gamified Learning

1. Introduction

Augmented reality (AR) in education and training is a rapidly developing research area, with potential to change pedagogical approaches of industrial training through experiential learning (Aguayo and Eames, 2023). In particular, the design process for creating engaging AR applications for education and training is important as it can affect how the learning is experienced (Chittaro and Buttussi, 2015) and consequently the effectiveness of trainee engagement in the experience. The importance of the design process for AR training experiences is also emphasised by Liu et al. (2019) comparative work between AR experiences and their physical alternatives.

Gamification within AR experiences positively influences user engagement (Dyulicheva and Glazieva, 2022; Eun, Kim, and Kim 2023; Plecher et al., 2018) and leverages it to deliver learning outcomes (Büttner, Prilla and Röcker, 2020).

Early design processes for industrial training AR serious games focused on purely design elements such as learning goals, storyline, and layout (Woll et al., 2011) before evolving to involve an outline of the development part of the process (Marinakis et al., 2021).

This paper contribution is a case study on the application of the design and development framework developed by Gilardi et al. (2021) on an AR serious game for industrial training. The value of this research is the introduction of techniques such as interaction rehearsal and the use of VR to design AR experiences to elicit feedback and contextualise the application for the stakeholders.

2. Related Work

Creating a serious game that contains elements of immersion has direct pedagogical benefits, such as engagement, and motivation (Chittaro and Buttussi, 2015; Plass, Homer and Kinzer, 2015). As such, AR technology is a good medium to increase immersion when paired with serious games (Dyulicheva and Glazieva, 2022; Eun, Kim, and Kim, 2023; Plecher et al., 2018). Experiential learning allows learners to experience, observe, and critically reflect about the subject matter as well as actively experiment with it (Kolb, 1984; Beard, 2022). XR experiences facilitate experiential learning as they provide learners with elements that support the stages outlined by Kolb (1984) and provide simulated hands-on experience and experimentation. Designing and developing such experiences is challenging, although differing design approaches have been applied by designers and developers, there is no clear established process for XR design and development (Krauß et al., 2022).

Implementing AR in an industrial setting to provide immediate feedback to the trainee can aid to prevent mislearning (Büttner, Prilla and Röcker, 2020) and help avoiding hazardous situations (Li et al., 2018). The lack of an established process for the design of AR applications can impact negatively on the learners' experience in comparison to identical tasks conducted physically (Liu et al., 2019). As such, understanding how to effectively design such applications is an important area of study.

Tooltips (Keating et al., 2011) and best practices (Dirin and Laine, 2018) for AR design are present in the literature to help designers in the process of creating an AR application, however, they lack a structural approach to the design of the experience. To address this limitation there have been attempts in creating early design frameworks, for instance, the one proposed by Irshad et al. (2015), which lacks clarity on where the stakeholders and potential users fit within the design process. Other frameworks focus more on the software implementation of the AR application such as the one proposed by Bacca Acosta et al. (2019). User-based studies approaches are also detailed within the literature (Gabbard and Swan II, 2008), however, these approaches do not focus on designing for educational applications.

Application design and development is also discussed within the literature, for instance, Woll et al. (2011) design approach is based on deriving learning goals, developing a storyline, and the arrangement of the application screens. The relationship between these elements forms the design of the AR application. Marinakis et al. (2021) initial stages are similar to Woll et al. (2011), however, they are followed by two additional stages, development and evaluation. The design goals of both case studies mentioned focused on motivating (Woll et al., 2011) and encouraging (Marinakis et al., 2021) the learners.

In contrast with Irshad et al. (2015), Woll et al. (2011) and Marinakis et al. (2021), the design and development framework proposed by Gilardi et al. (2021), see figure 1, focuses on education applications, involving stakeholders and potential users through the process. In the pre-design stage not only software requirements are identified, but also learning needs, learning goals, and integration of the output software within the teaching context. Each stage in Gilardi et al. (2021) framework feeds back to earlier stages, facilitating an iterative approach. Unlike Marinakis et al. (2021), where iterations of the design are conducted at the very end of the design and development methodology, or Gabbard and Swan II (2008), where the process is linear, Gilardi et al. (2021) approach allows for iterations to occur earlier on in the design process, thus providing early opportunities to refine the design with users and stakeholders and more chances to go back to previous stages, if additional requirements or changes are identified throughout the design and development process.

3. Methodology

The design and development process for SwageXR followed Gilardi et al. (2021). The three core areas of the framework can be derived as pre-design, design, and development. All areas require cooperation between the researchers, designers, developers, and industry stakeholders (managers, and instructors) as well as the trainees. As this paper focuses on design, we will limit our discussion to the pre-design and design stages, with development and evaluation to follow when these stages are completed.

After obtaining ethical approval, the design needs and requirements of the application were collected for the pre-design stage through a contextual design approach (Holtzblatt and Beyer, 2014) within an industrial training company. Contextual inquiry (Holtzblatt and Beyer, 2014; Drachen, Mirza-Babaei and Nacke, 2018) is the core of contextual design, and in this work, it was applied through the researcher posing as a trainee during a two-day training course at the involved company's training facility. Doing so allowed for observation and direct experience to be gained by the researchers, facilitating understanding of the existing training practices and the training culture at the company.

Semi-structured interviews (Lazar, Feng and Hochheiser, 2017) with four company training instructors were used to build upon the direct experience gained from the researcher's involvement in the course and the observations taken from it.

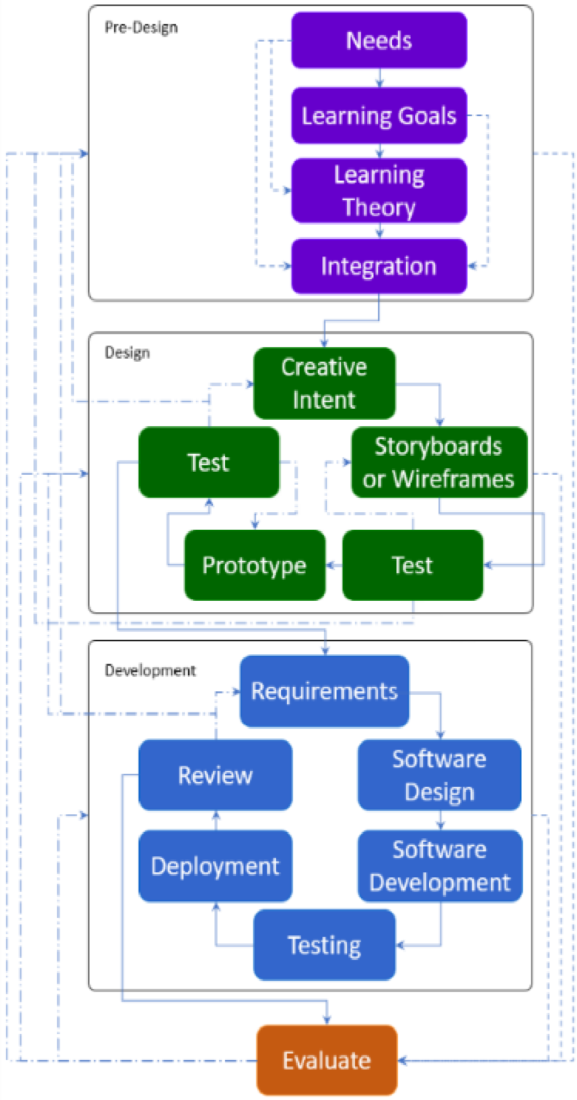

Figure 1: Application Design Framework Gilardi et al (2021)

Paper prototyping was used to elicit feedback from company technical director, who is responsible for overseeing the training course curriculum and the instructors that deliver it, via an unstructured interview (Lazar, Feng and Hochheiser, 2017). The 'interaction rehearsal' technique was used to help produce the paper prototypes.

A VR low-fidelity prototype of the AR application was designed based off of the paper-based wireframe and used in a workshop to demonstrate the AR application in context via a VR walkthrough. Data obtained from the walkthrough was factored into the design decisions and changes, which will be reflected in the prototype of the gamified AR application.

The techniques mentioned contribute to identifying needs, learning goals, and learning theory of the AR training application and the steps necessary to integrate the existing training course content into a gamified AR scenario.

Although it would have been ideal to involve trainees in each of the methods described in this section, this was not possible at the time due to the company requirements.

4. Design Process

Within this section, the design process focuses into the two parts which map to the design core areas of Gilardi et al.'s (2021) framework, pre-design and design. The application of this framework in this paper can be seen in figure 2. When reference is given to the roles of the research, designer, or developer, it should be noted that for the purpose of this paper, due to resource constraints, the same individual carried out these roles at differing stages of the design process.

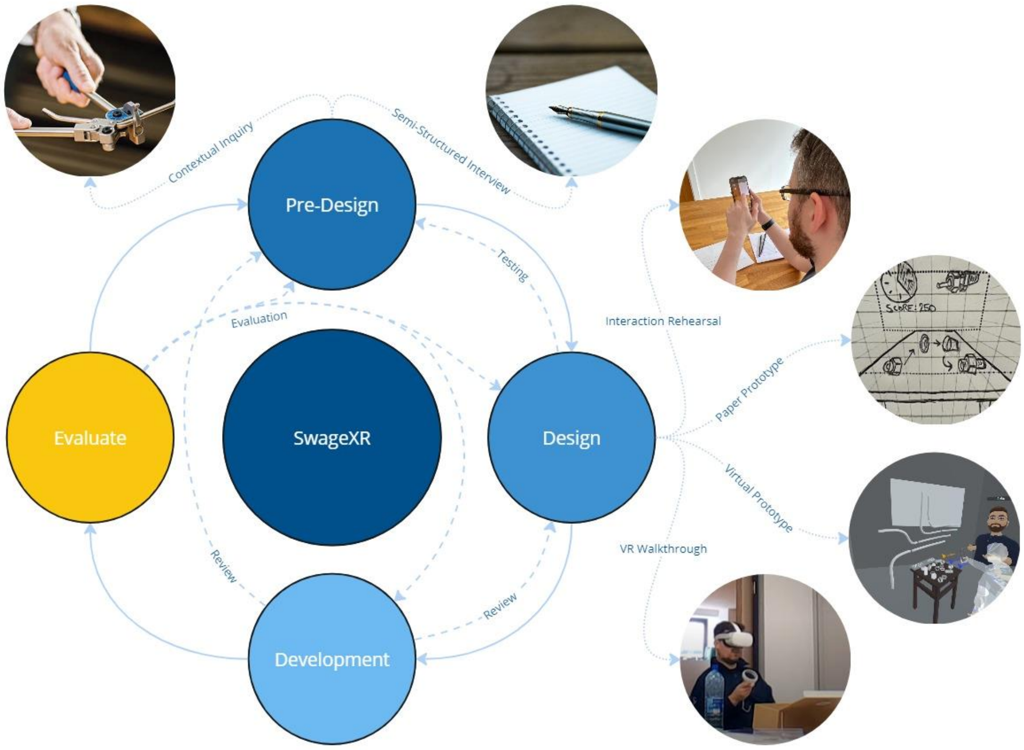

Figure 2: SwageXR Design Process Overview

4.1 Pre-Design

During the pre-design stage the focus is to gather information that contributes to understanding the needs, learning goals, learning theory, and how the AR application can be integrated within the training course.

In order to collect this information the researcher posed as a trainee on one of the company-taught two-day courses. The time spent posing as a trainee allowed for practical and theory-based exercises to be undertaken to develop an understanding of course content and the learning goals of each exercise. During this timeframe the researcher was also able to make in-depth observations about how the training is conducted and the culture within the company.

Observations from the exercises highlighted that a core task was identification and assembly of tube fitting components from four differing manufacturers. The fitting components required to be assembled in the correct orientation and order. The components had subtle differentiating features which is where the difficulty of this task resided. The simplistic nature of the task meant that when performed, it was quickly completed so engagement with the task was short. This was where the company wanted gamification to be introduced.

Semi-structured interviews were conducted with four of the instructors that deliver the course to the trainees supplementing the data collected during the contextual inquiry approach. Before the interviews there was no decision made on what XR technology will be uses for the application. Interview questions aimed at gauging the interviewee's experience with serious games and extended realities, identify what they considered to be some of the core elements of their teaching, and understand what part of the course was seen to be an essential part. During the interviews, discussions emerged around the trainers perceived vision of an ideal serious game and the benefits of it.

Through thematic analysis of the recorded interviews, it was gathered that the trainees needed an increased amount of engagement. Themes emerged on AR as the method of delivering the extended reality experience due to the trainee accessibility to a smartphone during the runtime of the course, and of what content would be considered core for the serious game. During the interviews discussion identified a theme of the spatial representation of how the AR scene could appear in various areas of the room. The insights suggest that there would be many trainees using the AR application at once, so it was important that the trainees did not get in the way of one another. Opinions of how the scene would appear would be to attach it to a plane such as the desks in front of each trainee.

Gamification options were discussed with the instructors with a theme emerging around real-time competition, in-line with the work of (Li et al., 2022). The discussions with instructors were leaning towards something that would be time-based with the potential to score dependant on progress. To add an additional layer to the real-time competition theme, a gamification idea of having a leaderboard was mentioned to increase the competitive nature of the application. The scope of this leaderboard was suggested to split into three categories for daily, monthly and all-time, the categories allowed for a competitive nature to be discovered by the trainees for not only the current training course, but with previous cohorts as well.

After the thematic analysis was completed the design decision of developing a gamified AR training application about tube fitting was made to address the need to improve engagement with the course and introduce something novel for the trainees. Experiential learning was selected as the pedagogy to help address this need (Liu et al., 2019; Aguayo and Eames, 2023).

After discussion with the course instructors it was agreed that the gamified AR training application will be integrated as a complementary element to the existing course structure when integrated alongside current practices, to facilitate engagement of trainees. Operationally, to access the application during the course, it was also agreed with the instructors and the technical director that a QR code will be visible on the trainee desks for them to scan.

4.2 Design

Based on the information gathered in the pre-design stage, the first design of the AR Serious Game took the form of low-fidelity prototype. At this point, the creative intent was to design a spatial environment that enveloped the training course learning outcomes (tube identification and assembly). Design considerations also involved how to effectively apply gamification to appeal to the training course trainees.

A paper prototype was developed starting with an 'interaction rehearsal' approach, also known as 'acting-out interactions', of the scenario (Gilardi et al., 2016; Dunlop, 2014; Masterclass, 2023) to give an idea of potential user movements and interaction when it came to planning out the scene on paper. Interaction rehearsal is performative interaction design approach that can be employed in the earlier stages of design, where the designer or the potential users physically act out the movements how they believe interactions should occur (Macaulay et al., 2006). Scoping of interactions is beneficial as design elements are made apparent that were not obvious without placing a person in the scenario, an example for AR serious games would be spatial awareness and restrictions and safety issues the user may encounter.

The preliminary scene design concept for the AR training experience was drawn on a 2D equirectangular grid, figure 3 left, before being scanned and loaded on a mobile device to be explored in more depth, figure 3 right.

The paper prototype gave early insight into spatial layouts and how the end user may perceive and interact with the elements of the prototype.

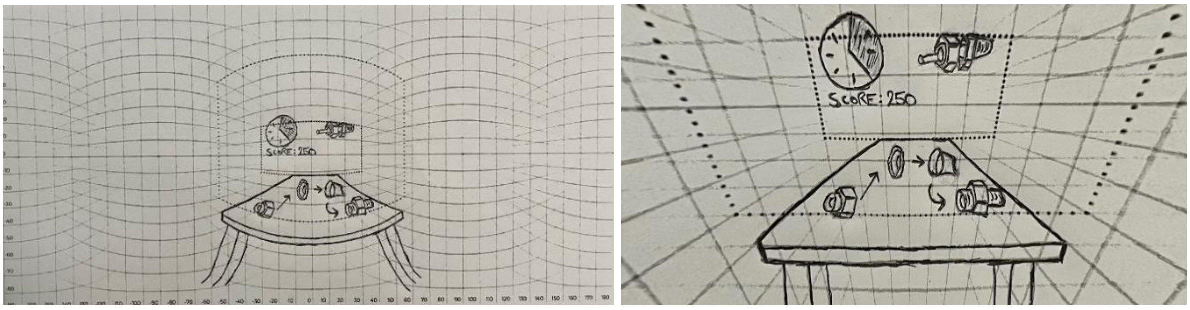

Figure 3: Left, one of the paper prototypes drawn on an equirectangular template; Right, same paper prototype applied to a 360 sphere, live version [here]

Following the paper prototype design, further creative planning was done through storyboarding (Leighfield, 2023) of the gamified AR training application layout (figure 4). Including, a splash screen, main menu, revision section, leaderboards, and the gamified challenge area containing the current paper prototype.

The technical director of the company participated in a feedback session where the application flow was presented, before engaging in a discussion regarding this stage in the design process. Feedback from this session highlighted the different considerations for interaction with the tubing components within the challenge and revision modes of the application.

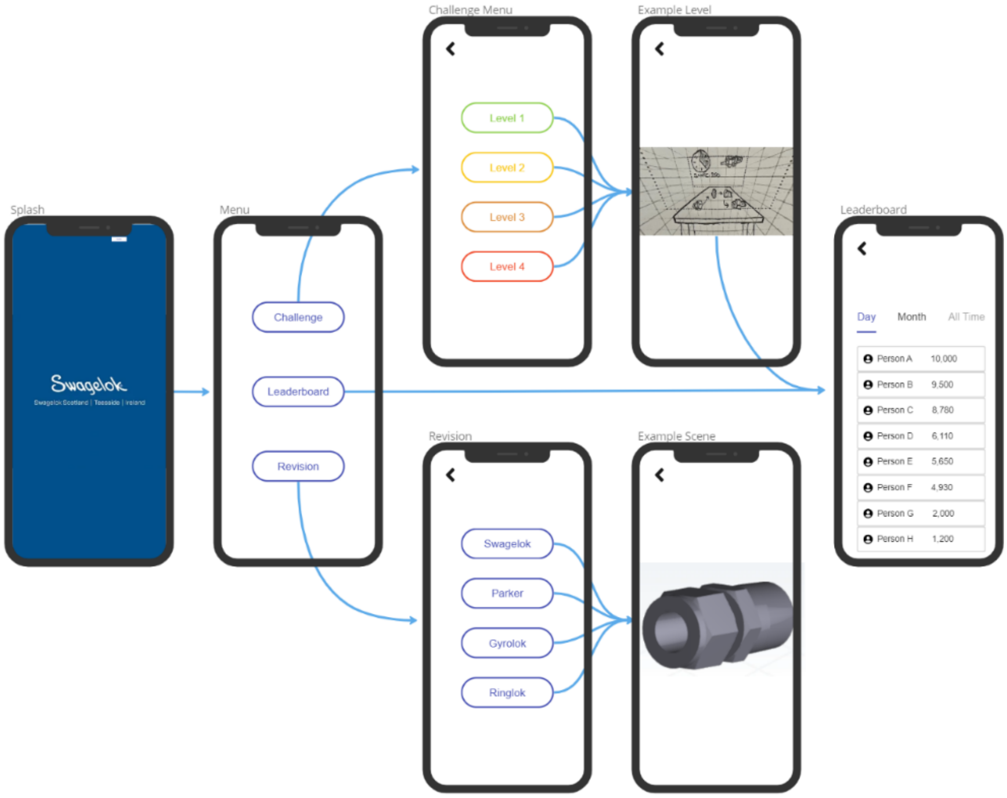

Figure 4: Storyboarding of the gamified AR application during pre-design stage

Highlighted areas included the need for trainees having immediate feedback within the component assembly challenge of the application was outlined, whether their actions are correct or incorrect. Moreover, the application will need to load different components each time it is loaded, to avoid trainees having the same training experience every time the app is used. As a result, a design choice was made to use procedural generation when loading components. Additionally, a new security requirement for the application was defined, with the gamified AR training application only being accessible at the training facility.

Based on the feedback session, a low-fidelity prototype was designed within ShapesXR (Shapes Corp, 2023), a tool to design prototypes within VR, figure 5, this involved creating a spatial environment resembling the space where training will take place, containing a progression of scenes for how a trainee would use the AR serious game. The VR-based prototype allowed for contextualising the AR application. The immersive element of this second prototype was beneficial as it allowed for those involved in its exploration to gain an additional understanding of how the gamified AR training application would function.

The VR workshop included the technical director and two instructors from the company as well as the designer. The workshop demonstrated the gamified AR training application design, utilising the 3D space within VR to convey intended movements and interactions of the user.

Figure 5: Four screenshots from the VR walkthrough of the gamified AR application. Showing trainee using QR code and security code (far left), the designer demonstrating functionality (left), correct configuration feedback (right), and the AR leaderboard (far right)

Critical information obtained from the workshop involved concerns surrounding how detailed the 3D models of the tube fitting components could be, as subtle detailing on the components was crucial for differentiating them. As a result, it was organised to 3D scan the fitting components to allow for higher quality models used within the AR application. Feedback from the workshop also involved the UI presented for the application and consisted of a reordering of elements on the menu.

4.3 Development

Data collected from the industry stakeholders allowed for the initial coded prototype requirements to be outlined. The development process of the coded prototype is still ongoing and follows an agile workflow (Dybå and Dingsøyr, 2008). The AR application targets both Android and iOS devices to ensure accessibility for trainees, whilst development is done within the Unity Engine using the XR interaction toolkit. When development of the coded prototype is concluded, review of its ability to increase trainee engagement with be analysed with a combination of initial experience playtests and usability tests (Drachen, Mirza-Babaei and Nacke, 2018).

5. Conclusion

This paper contributes to the field of XR application design by providing a case study about the XR design process of Swage XR, which builds on Gilardi et al.'s (2021) design framework. This case study applies Gilardi et al. (2021) to design AR training, adding interaction rehearsal techniques and VR pre-visualization as viable design methods. Such methods provide stakeholders with additional context regarding the final application at the prototyping stage. The additional context elicited further feedback from the company technical director and instructors that was not obtained during discussions around the paper-prototype.

Unlike the design processes of Marinakis et al. (2021) and Woll et al. (2011), the application of contextual design (Holtzblatt and Beyer, 2014) allowed for first-hand experience to be gained, which provided quick information uptake. Obtaining the knowledge about the training this way formed a baseline for understanding the training practices and what was required for the application design. This approach led to an interview process that focused on current training practices before undertaking low-fidelity prototyping.

One of the techniques used in this paper was 'interaction rehearsal', which in some ways is similar to the AR design approach taken by Thompson and Potter (2018), which used 3D printed props to let users' act-out AR interactions. Although similar to Thompson and Potter (2018), the approach taken in this paper did not use 3D props and was limited to the designer. Further exploration will involve using potential users during the interaction rehearsal stage.

Despite interaction rehearsal being limited to the designer, applying it to the AR scenario allowed for recognition of conceptual design issues, and ideas on how to address them. For instance, a recognised issue was that user interactions involving depth required the user to move with their device to reduce distance to objects in the AR scenario, potentially causing fatigue and safety issues. To address this, limiting the space of a user's physical environment to the desk in front of them meant that depth-based interactions could be conducted with more subtle device movement.

Two prototypes were created during the design process, a paper-prototype and a VR prototype. Paper-prototyping is a well-known approach for application design (Chandler et al., 2002; Lumsden and MacLean, 2008). In the field of XR this has been translated into using equirectangular templates to simulate space (Nebeling and Madier, 2019). The benefits of this approach are similar to traditional paper-prototyping, which allows to refine requirements and needs before committing to software prototyping. In terms of virtual prototyping, we took the approach of generating a VR scenario to contextualise the AR application. To the best of our knowledge, we are first to document this approach.

The VR scenario added the benefit of providing better understanding of spatial relationships between the AR application elements for the VR walkthrough participants, which allowed for more specific feedback surrounding AR interactions. The limitation of this approach is the need of VR equipment for the participants, which may not always be available to them.

A limitation of this work is that it did not involve final users (trainees) into the design process, this would have enabled to develop the application using co-design approaches, however, this was not possible to the company requirements.

Future work for this project would be to implement the design into a functioning AR application, which will allow for analytical methods to be applied to measure trainee engagement and learning, thus validating the design correctness.

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