Flexible XR Prototyping — A Sports Spectating Example

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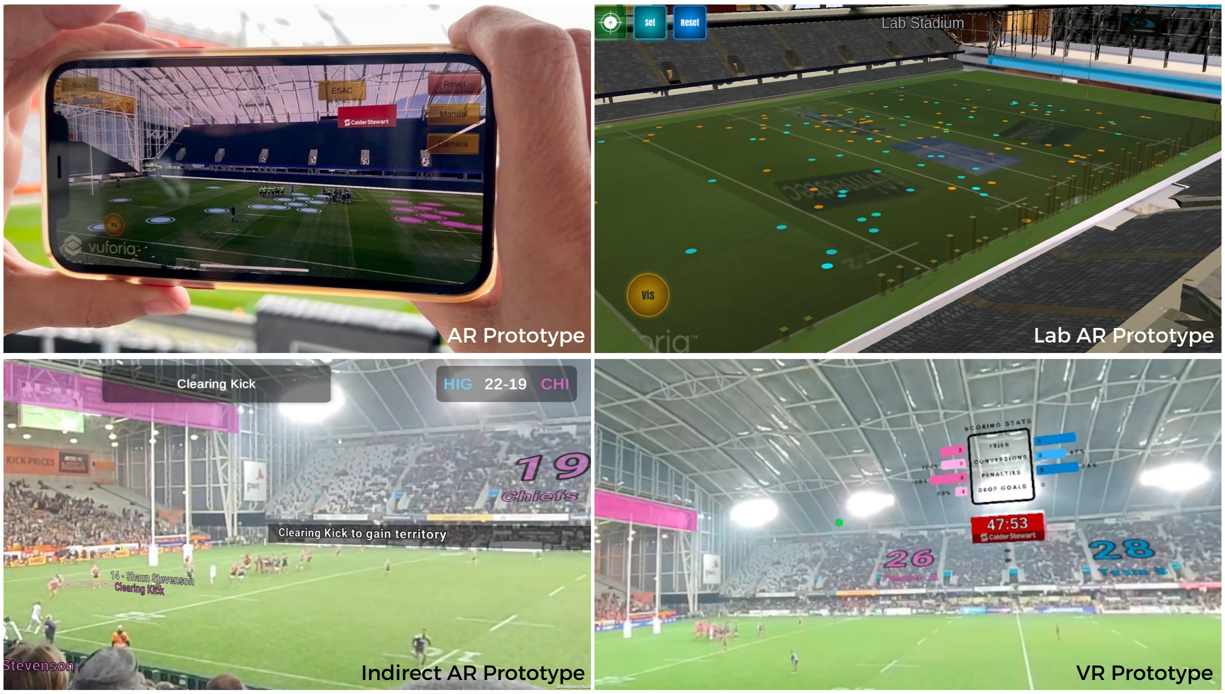

Figure 1: Using flexible XR prototyping for developing an AR sports spectating application. The four different cross-reality prototypes used in the process: (Top left) The stadium AR prototype is the targeted end product to be used on-site in the stadium. (Top Right) The miniature scale Lab AR Prototype spawns the stadium on a table-top scale and is used for demonstration and development purposes. (Bottom left) The mobile indirect AR approach let users experience a simulation of the stadium AR prototype remotely. (Bottom right) The VR prototype that is similar to the mobile indirect AR prototype but runs in a VR HMD for simulating the on-site experience more realistically and uses a different interaction method.

Abstract

Extended Reality (XR) prototyping is a useful way that has the potential to assist the AR application development process. It allows for off-site development and evaluation in cases where on-site access is challenging or even impossible. In this work, we summarize our Flexible XR Prototyping framework, showing the different phases and considerations needed for an improved and more effortless XR prototyping experience. We then show how this can be used for the example use case of AR sports spectating in a stadium and provide some examples of the different prototypes developed for an on-site AR sports spectating application. Our goal is to share our own experience in AR prototyping and to spark discussion on the XR prototyping process.

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

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1 Introduction

Augmented Reality (AR) [1] aligns virtual content coherently with the physical environment to provide more insights to a user. While plenty of AR applications can be used in any location by placing content on a reference plane [2, 7], other AR applications are designed to be used on-site in a specific location [3, 4, 10]. For these applications, developers design content to be in reference to a specific location, such as a factory [4] or a sports stadium [10]. This spatial aspect makes it more challenging to design an AR application as the location users are supposed to use the application often will be different from where developers create the application. Sometimes, it might not be easy to access the on-site location, or the on-site location might not be suitable as a temporary working environment for an application designer or developer.

One such example where this happens is the use case of on-site AR sports spectating. The main idea of AR sports spectating is to overlay event-related data in a stadium environment for spectators to consume through mobile devices and head-mounted displays (HMD). For such a use case, we can assume that content designers or app developers are based in an office away from the sports venue. During the development process, the event site of interest might not always be available for testing and debugging. In addition, each test would require travel time that might increase costs and increase development time. Thus, we realized that there is a need for an approach for off-site XR prototyping that supports the development and debugging process by replicating the on-site experience as closely as possible.

In our previous research, we proposed a Flexible Extended Reality (XR) Prototyping Framework [5] that meets all these requirements. While developing our AR spectating application, we used this framework to implement different AR and VR prototypes with different configurations. Here, we will provide examples of these prototypes developed with the XR prototyping framework and reflect on their requirements.

2 Flexible XR Prototyping

We designed a Flexible XR Prototyping Framework (Fig. 2) based on our own experiences developing an AR sports spectating use case. While our main focus was AR sports spectating, we designed the framework to be generalizable to other AR applications and cover the considerations, characteristics and components of flexible XR prototypes. The framework aims to help XR researchers create new prototypes without too many complications or interruptions later in development. Here, we provide an overview of how the framework operates based on the original publication [5].

2.1 Designing with Purpose

The framework starts with the planning phase, which we call 'Designing with Purpose". This phase is where researchers brainstorm in the early phases of the design on what prototypes are needed. They are based off three different aspects, the **locality, scale,** and **evaluations**.

The **locality** refers to where we intend to use the prototype. For example, if the application is meant for outdoor use [8], then it would be great to have a prototype that could facilitate testing during development, which is most probably held indoors. Hence, researchers would need to ask themselves if they need a kind of prototype they could use during development where it does not involve going on-site.

The **scale** of the XR prototype is also considered here. For our use-case, we work with large stadium environments. We then developed a smaller scale AR prototype called the *miniature lab AR prototype*, a table-top sized AR. This prototype allows for a relatively unconstrained movement around the stadium, which is usually not feasible in real life.

Lastly, there is **evaluations** which refers to both the researchers' and user study perspectives. If the developer of an AR application wanted to evaluate the visualizations of their on-site application, for example, they would need a prototype that can simulate the actual AR use case. In user studies, having an off-site prototype that simulates the on-site experience is also beneficial as it might help to reduce confounding variables such as noise from other people (e.g. the crowd in the stadium scenario) or unexpected events (e.g. during a sports game).

2.2 Characteristics

Now that we have considered what prototypes we need, the next phase is to consider what characteristics should all the prototypes have, regardless of which types of XR features the prototypes involve.

The key characteristic of working across prototypes is a **modular design**. A modular design allows for scalability while simplifying the development process. Developers could then think of different modules that can be shared across all the prototypes, like a base class. Ideally, one would make changes to one of the modules through these base classes, and the changes should reflect across all the various prototypes. While this method provides better consistency to the codes, it does come with the disadvantage where changes in one prototype might break the other without the developer knowing. Therefore, frequent testing is encouraged with modular cross-reality

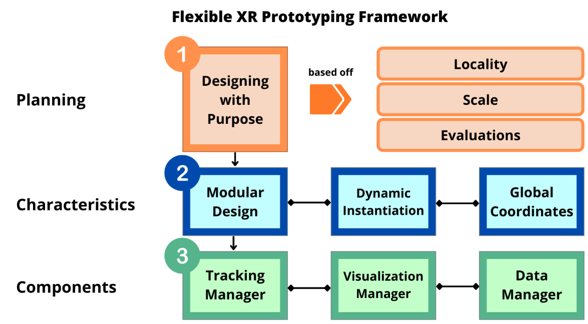

Figure 2: Flexible XR Prototyping framework: This framework guides researchers to have proper planning alongside the required characteristics and components for a flexible XR prototyping development process. Figure from [5].

prototypes. It is important to note that software engineering concepts like Continuous Integration and Continous Delivery (CI/CD) might be more challenging for XR and in particular here for AR as the testing often involves users/testers going to a specific site to fully test the application.

Another essential characteristic of a flexible XR prototype is to have **dynamic instantiation**. Especially in use case game editors like Unity are used, manual instantiation would mean dragging and dropping almost hundreds of game objects to its script across all the different prototypes. This method requires careful documentation, is time-consuming and is more error-prone, not to mention harder to debug. By creating prefabs and dynamically instantiating them via scripting, the amount of manual linking is lesser and would greatly benefit projects where visualizations and game objects are shared.

The last characteristic describes **global coordinates**. As AR research usually involves the definition and use of many different coordinate systems, all coordinates should refer to one global coordinate system, which is visible and measurable in the real world (ideally in a metric scale or being geo-referenced). In our use case, we used one corner of the playing field as our point of origin in the stadium; therefore, in all of our prototypes, the position vector (0,0,0) points to the same spot. This standardization assists in scenarios where there is object tracking data as an input source, in our case, player tracking data and event-based data. With this approach, all appropriate visualizations appear at the same position for all prototypes, reducing the trouble of individually translating incoming vectors to suit each prototype's coordinate spaces.

2.3 Components

The framework components are by-products of a modular design. A lot of AR applications share three essential aspects — tracking data, visualizations, and incoming data sources. While the aspects are not limited to the three described here and can be flexibly extended by other components (e.g. used for interaction or collaboration), we believe that a lot of AR applications are based on a similar structure. The tracking data refers to where the device is located in relation to the physical and virtual environment. In contrast, the visualization and incoming data both control the flow of data and the representation of data. Therefore, we propose the following three components: **tracking manager, visualization manager** and **data manager**. Each of them manages one important aspect of the AR application. Although different prototypes might have different tracking or visualization methods, they work similarly throughout the different prototypes in the base classes.

	Prototypes	Live view of the actual environment	Simulated Stadium Environment (by 360° video)	Implemented Use Cases	Tracking Methods (Implemented)
On-site AR	Stadium AR Prototype (Mobile/AR HMD)	✓		Assist on-site Viewing	Image Target Seat Localization Visual-inertia odometry
↑	Lab AR Prototype (Mobile)	✓		Off-site R&D assistance* Table-top remote viewing	Image Target Visual-inertia odometry
↓	Indirect AR Prototype (Mobile)		✓	Off-site R&D assistance*	On-device sensors
Remote VR	VR Prototype (VR HMD)		✓	Off-site R&D assistance* Remote viewing	On-device sensors

*Off-site R&D assistance refer to research, development, user evaluation and demonstration out of the stadium

Figure 3: A table showing the differences between the XR prototypes. The prototypes are sorted from an on-site AR application to a fully VR prototype that could be used anywhere.

3 Prototypes — Framework Implementation

Our research started with the focus on one prototype, which was the on-site AR prototype. However, we quickly realized that we needed other solutions for testing, out-of-stadium demonstrations and user studies. We need a prototype that allows us to explore and validate the visualizations we created, and we needed a prototype that simulates the on-site experience for the user studies. Hence, here we describe the four prototypes we developed, mainly mixed fidelity, each with its use-cases as shown in Fig. 3.

3.1 On-site Stadium AR Prototype

We started our implementations with an on-site stadium AR prototype (Fig. 1, top left). We consider this prototype to be very similar to the final product we develop in our use case as it is designed to be used on-site via a mobile device or an AR HMD. For this prototype, users see the action on the field through the camera or an optical see-through setup and get additional game-related information augmented on their field of view. As this prototype will be used in a stadium environment, registration and tracking methods play a crucial role in testing and debugging and deployment. Thus, there is a strong focus on integrating tracking managers with different options and testing these methods on-site as these components can only be tested on-site. As there are limited opportunities to access the stadium site, this prototype will receive less testing and debugging.

3.2 Miniature lab AR

During our development process, we noticed that it is often challenging to demonstrate the AR prototype to clients and partners as they would either need to come to the on-site stadium or were only able to experience a screen capture. Because of this experience, we decided to develop a portable, lightweight prototype that can be carried around to different locations while still conveying the features of the AR sports spectating application.

This miniature lab AR is a small-scale version of the final product, designed to be used in the laboratory or in situations where portability is needed (Fig. 1, top right). Utilizing a big A0-sized printed field with advertisement logos as an image target allows for a birds-eye view of the stadium model while still allowing the various visualizations to be shown. Due to the smaller scale, this prototype allows the user to have a “God mode” where they can walk around the stadium and view visualizations from different perspectives, including moving through the structure and viewing visualizations from inside the stadium. During our tests and demonstrations, we noticed that this feature was convenient for efficiently testing multiple perspectives.

3.3 Mobile Indirect AR

While the miniature lab AR prototype is effective for demonstration and testing visualization options, we noticed that the lab AR experience does not replicate the on-site experience well. The discrepancy in scale and birdseye perspectives create a very different experience. In order to address this problem and still be able to do testing and development in the lab while creating an experience similar to being in the stadium, we developed a mobile prototype that implements the concept of indirect AR [9].

The mobile indirect AR prototype shows a 360 representation of the stadium and overlays game-related graphics on top of it. The user can look around while rotating the mobile phone (Fig. 1, bottom left). We started using 360° panoramic photos captured in the stadium via a Ricoh Theta S[1] to simulate the spectators’ viewpoint, as the Theta S only takes low-resolution video. Upon upgrading to an Insta360 One X[2], we replaced still images with 360° videos. This allows users to look around the simulated AR environment where we place the situated visualizations. Depending on the scenario, different types of 360° videos were used, such as an empty field or an actual game. This prototype proved to be very useful in developing and testing visualizations as it is independent of the tracking challenges faced during an on-site testing environment or with the miniature lab AR prototype. In a user study, we analyzed whether users in a stadium using the on-site stadium AR prototype or the mobile indirect AR prototype with the same virtual content would judge their experiences differently [6]. We found no measurable difference and thus used the mobile indirect AR application as the leading prototype for demonstrations outside of the laboratory and user studies.

3.4 VR Prototype

To replicate the experience in the stadium the closest to the actual experience, we decided to move further on the MR continuum towards VR. Our VR prototype continues the mobile indirect AR prototype but is used in a VR headset (Fig. 1, bottom right). This prototype aims to recreate the closest experience to using an AR HMD in the stadium without needing to localize the user. By using the indirect AR prototype in a VR headset, users can turn their heads around to look at the stadium surrounding while spectating a pre-recorded 360° video of a game alongside situated visualizations. Due to the lack of a reachable touch screen, this prototype forces the testing of alternative interaction methods as would happen when using an AR HMD, where users cannot interact via touch screens. This prototype also retains the advantage of the mobile indirect AR prototype, which eliminates tracking and localization issues compared to the other prototypes.

4 Summary

In this paper, we provided an overview of a Flexible XR Prototyping Framework and reflected on how we used this framework to create different prototypes on the MR spectrum in the use-case example of on-site AR sports spectating. Our goal is to contribute to the discussion on how to make cross-reality prototyping easier and maintainable, seeing that it is much easier to maintain multiple prototypes if they are well thought out. It would also allow for easier content placement and synchronizing across all prototypes. We hope that future research will further explore this area and will further extend the work we have done.

Acknowledgments

This project is supported by an MBIE Endeavour Smart Ideas grant. We thank Animation Research Ltd, Forsyth Barr Stadium, the Highlanders, Otago Rugby (ORFU), and OptaPerform for their support. We also would like to thank our HCI and Visual Computing labs members.

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[2] Insta360 One X, https://www.insta360.com/product/insta360-onex/

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