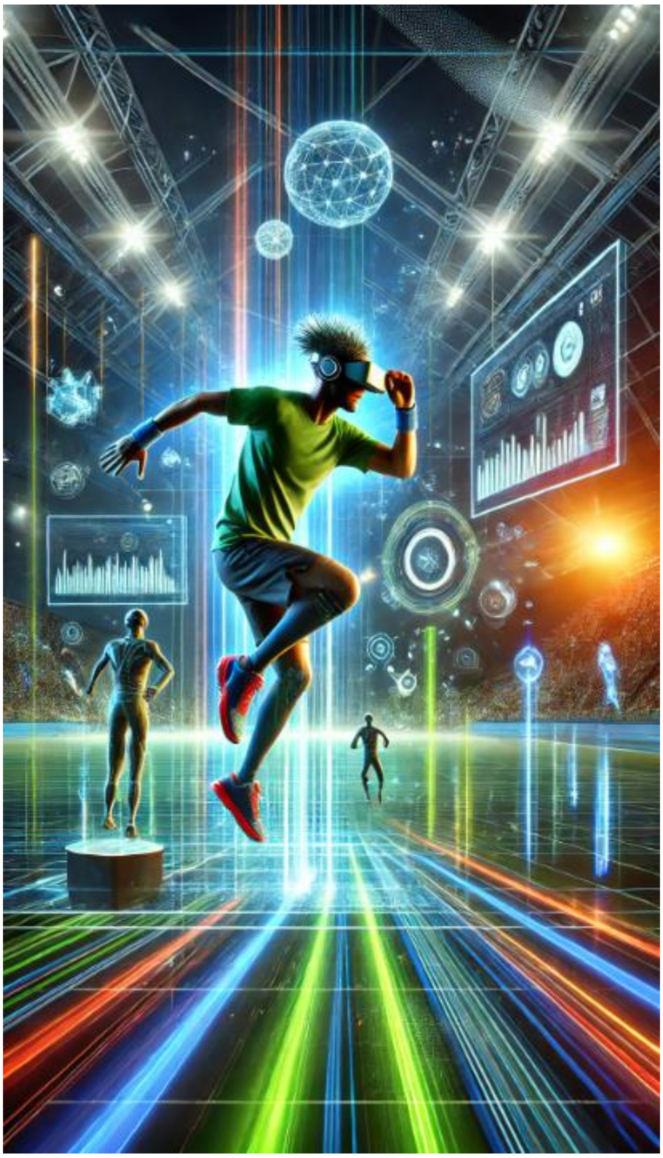

Extended Reality for Improving Sports Performance: A TOE Analysis of XR Adoption in Prominent Sports Organisations

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Extended reality, sports performance, metaverse, technology adoption, TOE-framework

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Abstract

High-performance sports organisations could gain a competitive advantage through the many opportunities digital transformation provides. Developments in the metaverse and extended reality (XR) are promising for performance sports but scarcely researched. Whereas specific applications of extended reality have been studied to measure performance improvements of athletes, there currently seem to be no managerial guidelines for its implementation within sports organisations. This paper aims to fill that gap, by mapping the current usage of extended reality and discussing both facilitators and inhibitors for the adoption of XR. A holistic analysis of technology adoption is provided by utilising the Technology Organisation Environment (TOE) framework. The research is carried out through a comparative case study of three prominent high-performance sports organisations. The case study is conducted by means of semi-structured interviews. Eight facilitating or inhibiting factors for the adoption of XR have been identified. The identified factors are digital strategy clarity, innovation pressure, network strength, budget, management support, user support, software development capabilities, and XR applications maturity. Additionally, the current state of the industry is discussed, revealing an industry in its experimental phase: the potential of XR for sports organisations is high, but the realisation of this potential is constrained by a lack of strategic priority, limited organisational readiness, and low technological maturity. The findings contribute to a better understanding of how XR adoption can be improved and underline the importance of the organisation's vision for XR adoption.

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1. Introduction

High-performance sports organisations are continually seeking innovative ways to gain a competitive edge in competitions. One example is the former pro-cycling team Sky, known for their approach of achieving 'marginal gains' through meticulous improvements across all aspects of performance.[1] Over the past two decades, the integration of (digital) technology in such organisations has moved from being experimental to mainstream. First, by employing basic tools like power meters and GPS trackers in cycling to track performance. These have advanced into cutting-edge technologies, such as machine learning algorithms that offer tactical analyses of players or teams. These developments reflect the broader global trend of digital transformation: the process by which organisations integrate digital technologies to fundamentally reshape their operations. This transformation has been widely studied and has had a profound impact on various industries, including the sports industry (Wang, 2024).

A notable concept emerging from digital transformation is the metaverse: a virtual world that parallels and integrates with the physical one (Zhao et al., 2022). Lee et al. (2021) describe the metaverse as a convergence of the internet and extended reality, creating an immersive cyberspace where physical and digital realities blend seamlessly. Advances in enabling technologies, such as high-speed connectivity (e.g., 5G) and next-generation hardware (e.g., Meta Quest Pro and Microsoft HoloLens 2), are accelerating the development of metaverse solutions. These innovations are driving increased user acceptance across both consumer and industrial applications. For instance, NVIDIA Omniverse[2] exemplifies how metaverse platforms are transforming industries by enabling real-time collaboration and simulation through the integration of digital environments with real-world data.

With multi-billion-dollar investments from companies like Microsoft and NVIDIA, industrial leaders are driving the rapid development of the metaverse (Catzel, 2024; Kerris, 2021). However, its applications within the sports industry remain limited. Most initiatives focus on marketing, such as Nikeland[3], a platform launched by Nike on the Roblox infrastructure, where users can try virtual products, play mini-games, purchase NFTs, and create custom items (Demir et al., 2023). The use of the metaverse for performance improvement in sports remains largely conceptual and is yet to gain widespread acceptance. A platform incorporating several metaverse-like features to enhance performance is the cycling platform Zwift[4]. Zwift provides its users, ranging from amateur enthusiasts to elite athletes, with a virtual environment where they can create detailed user profiles and compete against others. While the platform includes real-life physical attributes (e.g., body weight and fitness level), it also incorporates game-like progression systems, such as earning points to unlock power-ups. Despite these features, Zwift lacks a truly immersive environment, which is a core element of the metaverse. Immersion is particularly relevant for sports performance improvements, as it enables the realistic simulation of real-world scenarios. Achieving this level of digital immersion relies on technologies collectively referred to as extended reality (XR).

The topic of using XR for sports performance improvement is becoming increasingly popular, but research is fragmented (Zhao et al. 2022). Most studies to date have focused on the operational level within sports organisations, examining the usability of specific XR applications for purposes such as real-world representation, skill transferability, and injury prevention (see Table 10 in Appendix A). This is depicted as area A in Figure 1. Yet, to the best of our knowledge, discussions of extended reality for high-performance sports organisations at a strategic level are almost non-existent. High-performance sports organisations are big organisations, with extensive management layers[5,6]. Research

[1] https://youtu.be/THNBIQenywc?si=3wvVB6wn3X65wTPX
[2] https://www.nvidia.com/en-eu/omniverse/?
[3] https://www.nike.com/in/kids/nikeland-roblox
[4] https://www.zwift.com/home
[5] https://www.ajax.nl/club/organisatie
[6] https://www.teamvismaleaseabike.nl/team/?type=staff

should thus not only focus on empirically testing the XR applications themselves, but also provide findings which can be used at decision-making levels higher in the hierarchy of the organisations.

The recent emergence of this technology implies that organisations have not had the chance to (completely) implement the technology yet, making the topic of adoption especially relevant for XR. There have been studies conducted on how extended reality is adopted (Shahzad et al., 2024; Zweifach & Triola, 2019), however, these have not been aimed at the sports industry (area B in Figure 1). The sports industry is different than many commercial industries, since organisations operating in this industry do not only aim to be financially viable, but also have sportive performance goals. Technology adoption, especially those technologies aimed at improving sports performance, might thus have different factors influencing it than those discussed in current research. This is substantiated by other studies that research technology adoption specifically in the sports industry (area C in Figure 1), underlining the uniqueness of this industry (Abeza et al., 2022; Best et al., 2021; Saengchai et al., 2019).

This leads to the research gap this study is aiming to fill, depicted as area D in Figure 1. The sports context specifies which XR applications are relevant, and how they should perform. Furthermore, the sports context is different than others for technology adoption practices, given the dual objective of these organisations. The intersection of these fields leads to a novel research topic: extended reality adoption in high-performance sports organisations.

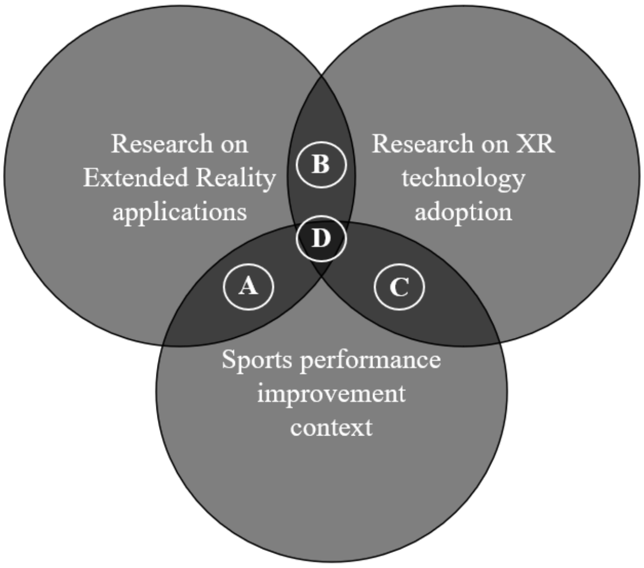

Figure 1. Identifying the Research Gap

The aforementioned research gap is studied by conducting a comparative case study research on sports organisations. Three prominent sports organisations are discussed in this study. The cases are explained in detail, but are anonymised to protect the sensitive information provided. The research of these organisations is structured along the Technology-Organisation-Environment (TOE) framework. This framework is used in other works regarding digital transformation and technology adoption, and is established as an adaptable and useful framework to research this topic (Abeza et al., 2022; Abdurrahman et al., 2024; Nguyen et al., 2022). The adaptability of the framework is useful, given the explorative nature of the topic. The methodology (see Chapter 3) expands further on the choice of the framework.

The TOE-framework has three dimensions. The ‘technology’ dimension provides an extensive overview of the technology (XR). The ‘organisation’ dimension concerns the way organisations are structured. The last dimension, ‘environment’, refers to competitive and regulatory pressures, and to supporting infrastructure to implement a technology. These three dimensions combined provide a holistic image of XR adoption in sports organisations. The comparison of the themes identified by the TOE-analysis of the three sports organisations illustrates which factors aid or hinder their XR adoption practices. This is also the research question of the paper: *What are the inhibitors and facilitators for high-performance sports organisations to adopt XR technologies?* A secondary goal of the research is to *map the current state of XR adoption by sports organisations*, to illustrate the current usage of XR within the sports industry.

In this study, the organisations that are studied are high-performance sports organisations. These will be referred to as sports organisations in the remainder of the article, but do not encompass amateur or recreational sports organisations. These organisations likely have different motivations, structures, and processes in place, and are thus out of the scope of this study.

The research provides a novel contribution to the literature in three ways. The current body of work on digital transformation is expanded upon. While the digital transformation of industries has been widely studied, its application within sports organisations, particularly at the strategic level, is underexplored. This research extends theoretical models by adapting them to the dual objectives of financial and athletic performance that are unique to the sports context. Secondly, the study provides an extension of technology adoption frameworks. By providing empirical insights into the drivers and inhibitors of XR adoption in high-performance sports, the TOE-framework is refined for applications where organisational readiness, technology maturity, and industry-specific pressures are significant. Lastly, by categorising XR applications for high-performance sports, the study develops a structured understanding of how immersive technologies can enhance athlete performance, skill development, and injury prevention. This categorisation serves as a foundation for future research into XR's role in sports.

The findings of this study have a practical relevance by providing the management of sports organisations with a useful overview of factors to consider when implementing extended reality into their organisation. The identification of specific facilitators and inhibitors provides actionable insights for managers seeking to utilise XR to improve athlete performance. These insights can help managers anticipate challenges and strategically allocate resources. Furthermore, the identified categories of extended reality applications provide managers and coaches with a clear overview of how XR can be utilised. Lastly, the comparative case studies illustrate how three prominent sports organisations adopt and utilise XR, providing a benchmark for other organisations.

The structure of this thesis is as follows: Chapter 2 synthesises the literature on extended reality in sports and defines the key concepts. This chapter also introduces a novel categorisation of the various applications of XR in sports. Chapter 3 presents the theoretical framework along which the research is structured and outlines the research methodology, providing details on the approach and methods used. Chapter 4 explores the individual cases of the sports organisations, offering insights into their practices and experiences. Building on these cases, Chapter 5 identifies and discusses the facilitating and inhibiting factors influencing XR adoption. Finally, Chapter 6 concludes the thesis by summarising its key findings and contributions to both theory and practice.

2. Literature Review

This chapter includes the definitions of the main concepts, providing a theoretical understanding of the components central to the research. To establish the theoretical foundation for this research, a systematic literature review was conducted. The purpose was to identify relevant studies addressing the intersection of sports and extended reality (XR) technologies, which are central to this study (see Figure 1). This helped with identifying the range of XR applications currently in use by sports organisations and their implementation processes. This is related to the secondary goal of this study; mapping the current state of the industry. This information aided the framework development and background information for the study. The process of the paper selection is outlined below:

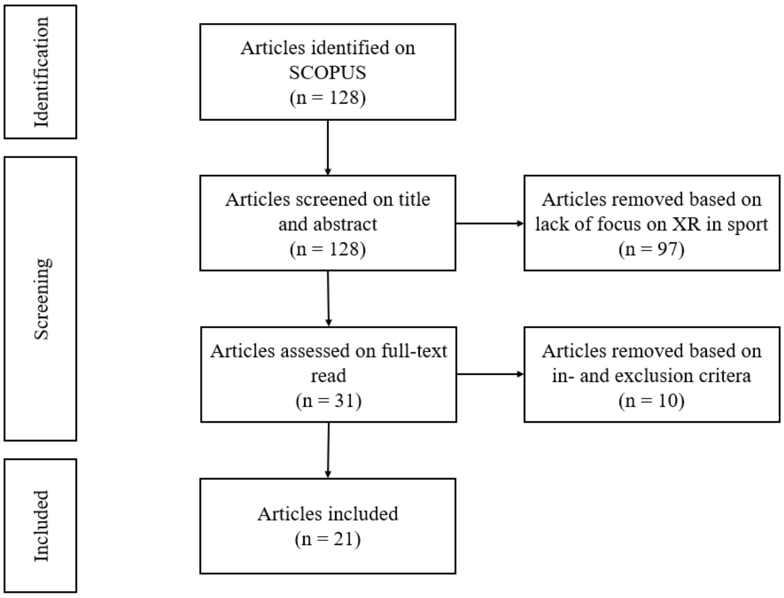

Figure 2. Article Selection

The review was conducted using search database Scopus, chosen for its interdisciplinary coverage across fields such as medicine, psychology, business, and IT. A structured search query[7] was constructed to identify relevant papers. The keywords used were: “Sport*” AND “Extended Reality” OR “XR” OR “metaverse”. These keywords were applied to the fields of TITLE, ABSTRACT, and KEYWORDS (TITLE-ABS-KEY) of the papers. The wildcard (*) ensures the inclusion of variations of the term "sport," such as "sports" and "sporting". The initial search returned 128 papers, to which a two-step screening process was applied. First, papers were reviewed to determine relevance based on their focus on XR applications in sports. This step reduced the pool to 31 papers. The remaining papers were read in full to assess their alignment with the inclusion and exclusion criteria. This resulted in a final sample of 21 papers that were included in the review, which comprised review studies (9) and empirical studies (12). This selection process is graphically depicted in Figure 2. The review studies provide a comprehensive overview of XR applications in sports, and the empirical studies concern the development and/or testing of specific XR applications in sports contexts. A detailed summary of included papers is available in Table 10 in Appendix A. The goal of this literature search is to gain an initial understanding on the different XR-applications used by sport organisations and their implementation. The included papers do not cover all existing research, as the keywords are

[7] https://www-scopus-com.ezproxy2.utwente.nl/results/results.uri?sort=plf-f&src=s&st1=%22extended+reality%22+or+%22XR%22+or+%22xr%22+or+%22metaverse%22&st2=%22sport*%22&sid=8b3e0a8d5b56a8116cc27d4618b771ca&sot=b&sdt=b&sl=94&s=%28TITLE-ABS-KEY%28%22extended

limiting in their scope (e.g. a paper concerning a *mixed* reality application for performance sport might not be included).

Table 1. Inclusion & Exclusion Criteria

Inclusion criteria	Exclusion criteria
Study focuses on XR technologies (VR, AR, MR, metaverse)	XR technologies are discussed for purposes other than sports improvement (e.g. marketing or fan engagement)
The purpose of the XR technology is to improve the performance of athletes	

2.1. Metaverse

The metaverse is a concept that was first coined in 1992 in the novel *Snowcrash* by Neal Stephenson, but has gotten more mainstream attention with the development of improved hardware solutions over the last few years. It represents a next step in the development of the internet, with new ways of connecting with each other through an immersive environment (Li et al., 2022). There is no clear consensus on a single definition of the metaverse, partly due to its novelty (Effing, 2024). It is seen as a (digital) alternative world in which users can fully immerse themselves (Zhao et al., 2022). Despite the lack of clarity on the concept, there are some key constructs identified by the literature. These are summarised by Effing (2024): the first construct is *interoperability*, which refers to the integration of diverse cyberspace into a unified 3D layer. This is a foundational element for the metaverse to function as a cohesive network rather than isolated virtual islands. *Digital twin capability* entails the possibility to create a virtual counterpart of a real-world environment. This facilitates the simulation of real-world scenarios in the metaverse, enabling immersive and realistic experiences. Another important construct is that of *gamification*. By incorporating features like challenges, rewards, and interactive narratives, users are attracted and retained. Users should be represented as *universal avatars* in the metaverse. These avatars are more than just visual stand-ins; they carry identity and personal data. This further highlights the metaverse's aim to bridge physical and virtual identities. Lastly, the metaverse should have a *traceable digital economy.* The metaverse is expected to have a robust digital economy characterised by secure and transparent transactions. Technologies like blockchain and non-fungible tokens (NFTs) enable the verification of ownership, digital trade, and the creation of new economic models. The metaverse is not just a technological development, as it has the potential to reshape industries (including the sports industry) by merging physical and virtual worlds.

The concept of the metaverse is already utilised within the sports industry. Metaverse applications currently mainly focus on marketing, broadcasting, or fan engagement. The number of metaverse platforms related to the sports industry is increasing. For the Winter Youth Olympics of 2024[8], fans could for example watch and conduct interactive experiences in a metaverse, such as virtual tours of venues and mini-games against other users. This reflects the gamification and universal avatar constructs. Another example is the Alfa Romeo Formula One team[9], which has engaged with its fans through metaverse experiences since 2023. Among others, this metaverse application includes a virtual version of the Alfa Romeo car, part of the digital twin capabilities construct. The NBA Topshot platform[10] allows users to trade in NFTs from players in the NBA league, resembling elements of a traceable digital economy. This illustrates that the metaverse constructs defined by Effing (2024) are reflected in current sports metaverse platforms. What is lacking, however, is a single sports metaverse that includes all constructs.

[8] https://olympics.com/ioc/news/gangwon-2024-has-launched-the-first-ever-metaverse-experience-for-youth-olympic-fans
[9] https://www.blackbookmotorsport.com/news/alfa-romeo-f1-team-metaverse-everdome-hoko-agency/
[10] https://nbatopshot.com/

This study does not focus on all key constructs of the metaverse. Rather, it focuses on one of the enabling technologies behind the metaverse: extended reality. Extended reality allows the user to immerse themselves in a digital environment, or add digital elements to the real world. This is a vital part of the metaverse, enabling realistic immersion in the digital world where the other metaverse constructs (such as a traceable digital economy) are integrated.

2.2. Extended Reality

Extended reality is the overarching term used for virtual reality (VR), augmented reality (AR), and mixed reality (MR) (Noury et al., 2022; Wirth et al., 2022). These different types of 'reality' vary from entirely replacing the real environment with a digital one, to an environment in which digital objects are placed that can interact with the real environment (Noury et al., 2022). This spectrum is depicted in Figure 3. Much research has been done into VR/AR/MR, hence in this article only a basic explanation is provided for each type of 'reality'.

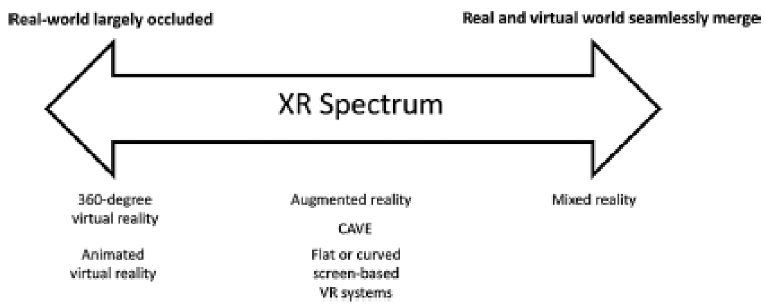

Figure 3. Spectrum of XR (Noury et al. 2022).

2.2.1. Virtual Reality

Virtual reality involves fully immersing the user in a digital environment, removing the real-world completely. Virtual reality exists in two versions: Animated VR and 360-Degree VR. In Animated VR, the virtual environment is animated and users can interact with it (Kittel et al., 2020). The virtual environment can be manipulated to mimic real-world scenarios. In 360-Degree VR, the digital environment that immerses the user is a pre-recorded video from the real-world (Kittel et al., 2020). This increases the perceived realism, however, the user is not able to interact with the virtual environment. For both virtual reality versions, the user is wearing a head-mounted display (HMD), such as the Meta Quest Pro[11]. There are also VR-solutions that do not require an HMD, such as a CAVE-system or screen-based VR systems. In a Cave Automatic Virtual Environment (CAVE) system, the user is in a room where digital images or videos are projected on the surrounding walls (Molina et al., 2022). A screen-based VR system works similarly, only has screens rather than projecting systems. Molina et al. (2022) compared CAVE-systems and HMD-systems, and found that HMD-systems are generally preferred regarding natural hand interaction. HMD-systems are currently also more commonly used in research and practice. This article will focus mainly on HMD-systems.

Both versions, Animated and 360-Degree, of virtual reality have the potential to improve sports performance, although only Animated VR is used in the selected literature. This is likely because the ability to manipulate the digital objects in the immersive environment is valuable for elite sports. It can be used to simulate competition environments, practice sport-specific elements, practice non-specific elements (e.g. cognition), and help with injury rehabilitation (see Table 2 later in this chapter).

[11] https://www.meta.com/quest/quest-pro/

Figure 4. Animated VR (Electronic Arts, 2022) and 360-Degree VR (PARSL3Y, 2017)

2.2.2. Augmented Reality

When using augmented reality, an information layer with digital objects is overlaid, in real-time, on the real-world (Wirth et al., 2022). The digital objects do not interact with the real environment. For example, a digital ball that falls from the air to a table, will pass through the table as if the table is not there (Noury et al., 2022). It is also possible to occlude objects from the real environment, rather than just add them (Wirth et al., 2022). AR experiences are commonly delivered through specific AR glasses, like the Microsoft HoloLens, but can also be created through a regular smartphone or tablet.

Augmented reality is mainly used to train tactical situations. For example by augmenting players on a football pitch (Kim et al., 2022). Many other applications that augment digital objects on the real world are actually mixed reality, which is elaborated upon in the next section. For fan engagement, there are many known augmented reality applications: e.g., player statistics that are projected, or banners with customized advertisements besides the sports field. This is, however, out of scope of the research as it does not focus on athlete performance.

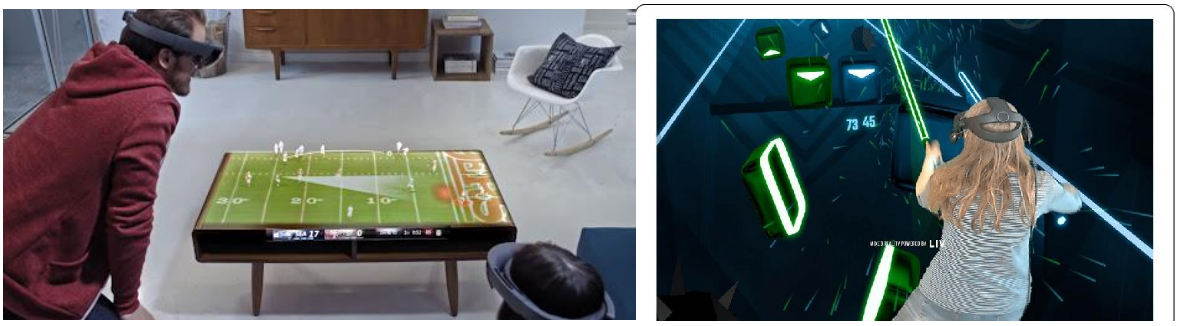

Figure 5. Augmented Reality (Martindale, 2016) and Mixed Reality (Erhardsson et al., 2020)

2.2.3. Mixed Reality

Mixed reality can be considered an extension of augmented reality, where the digital objects can interact with real objects. It bridges the gap between animated VR and augmented reality, by enabling real and digital objects to coexist and interact. Taking the example from augmented reality, the digital ball can now bounce up and down on a (real) table surface (Noury et al. 2022). Unlike AR, MR applications cannot be delivered through a smartphone or tablet. It requires specific headsets, such as the Microsoft HoloLens 2. These devices employ advanced technologies such as spatial mapping, eye tracking, and hand gesture recognition[12].

This technology has elaborate applications for the performance sports domain. The ability for MR applications to interact with the real-world provides a lot of opportunities. For example, a digital goalkeeper can respond to the kick of a striker in a penalty training scenario. This extensive usability for sports is reflected in the literature, as MR is used for providing real-time feedback, practicing sport-specific elements, and training non-sport specific elements (see Table 2).

[12] https://www.microsoft.com/en-IN/hololens/hardware#document-experiences

2.3. Extended Reality for Improving Sports Performance

The different types of extended reality (VR/AR/MR) appear to be useful for improving sports performance, as is discussed in the sections above. Research into this domain is still in its infancy, but recently gaining more attention by the scientific world, as the number of articles published on the topic is increasing (Zhao et al., 2022; Wirth et al., 2022). Many insights from other domains (e.g., medical or military) have been used as starting points for research into XR-applications for elite sports (Noury et al., 2022). For example, Post Traumatic Stress Disorder (PTSD) treatments using VR have substantiated the ability to simulate an environment that provokes the user, something that in turn is researched for sports by mimicking competition pressure (Noury et al., 2022).

The definition of sports performance is highly dependent on the context, for a football player who is playing offensive it might be scoring goals, and for a goalkeeper stopping those goals. In cycling it can be a fast time on a time-trial, or good bike handling skills on a technical descent. It is common to distinguish between task-oriented goals (improving bike handling) and outcome-oriented goals (winning the race) (Nicholls, 1984). Naturally, the end-goal is to improve the amount of positive outcomes. However, in order to do so, the task-oriented goals must be met. Extended reality is suited to improve specific elements of sports performance, aligning with the concept of task-oriented goals.

Moreover, sports performance is multi-faceted. Physiological, biomechanical, and psychological variables all interact with each other to determine the sports performance (Glazier, 2017). Davids et al. (2003) developed the Dynamic Systems Theory, which highlights how performance emerges from the interaction of an athlete's constraints (e.g., physical abilities), task demands (e.g., scoring goals), and environmental factors (e.g., competition conditions). Extended reality is able to fulfil a role in improving all three of these components. Athlete constraints can be improved through specific practice applications, which can, for example, improve reaction times. Task demands can be enhanced through immersive game scenario replication. Lastly, the athlete's ability to cope with environmental factors can be improved through realistic simulations that prepare the user for various scenarios, e.g. bad weather or a discouraging crowd. This theory underlines the varied factors that influence and make up sports performance.

2.3.1. Organisations Defined

As referred to in the introduction, the usability of XR technology for sports organisations depends on the organisations themselves and the companies producing the required technologies. There are three key stakeholders, as inferred from the literature and web searches. Sports organisations are defined in this article as organisations that perform professionally at the highest level in their respective sport(s). The organisation should include athletes, a support staff, and a management. The athletes can also be a member of the organisation indirectly, as is the case for a sports federation. Technology developers for XR are defined as companies that produce hardware or software that is required for developing XR. The application developers act as intermediaries, and build upon the initial hardware and software developed by technology producers to create applications that can be used by sports organisations. The technology and application developers together form the technology producers. These definitions are used for company selection, as described in Chapter 3.

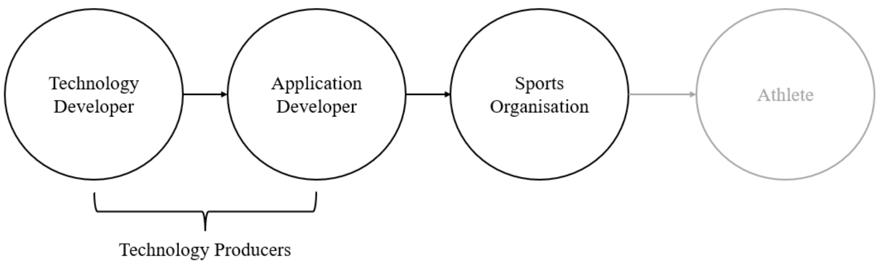

Figure 6. Key Stakeholders for XR Adoption in Sports Organisations

2.3.2. Categories of Sports Performance Improvement

From the selected literature, seven different categories are identified for using extended reality in enhancing the sport performance. The categories of XR usage to improve sports performance were developed through a systematic, inductive process based on the analysis of the 21 selected papers. First, each paper was carefully read, with a focus on identifying specific use cases of XR in sports. Notes were taken on the XR use cases in each study. Next, similar use cases were grouped into clusters based on their shared purpose or mechanism. For instance, applications focusing on training physical actions were grouped under *motor skills*, while those addressing decision-making in specific scenarios were clustered under *tactical analysis*. The final categories were validated by cross-referencing them with the original notes and papers to ensure all identified use cases were represented and accurately categorised.

This process resulted in seven categories, each representing a distinct way XR is used to enhance sports performance. These categories, along with their explanations and supporting references, are summarised in Table 2. Besides the categories, the finding is made that there are relatively few authors who are responsible for the majority of the existing research. This can be an indication that the research topic is still in its infancy (Singh et al., 2022).

Table 2. Categories for Extended Reality Usage in Sports Performance Improvement

Category	Short explanation	Papers
Cognition	Cognitive skills, such as hand-eye coordination and reaction speed, can be improved by immersive training environments. This is not sport-specific, but can positively impact performance in (some) sports.	Richlan et al (2023), Noury et al. (2022)
Motor skills	The mind-muscle connection is trained to perform specific actions or movements. This can be either sport-specific or in general.	Noury et al. (2022), Geisen and Klatt (2021), Heo and Kim (2021), Geisen et al. (2023), Richlan et al (2023)
Real-time feedback	Feedback is provided on the movements of an athlete. This can take over or enhance the role of the coach and improve learning by the athlete, as it is in real-time.	Geisen and Klatt (2021), Lee et al. (2023), Geisen et al. (2023), Orlandi et al. (2023), Geisen et al. (2022)
Tactical analysis	Athletes and/or coaches can immerse themselves in a specific situation, either self-created or from a previous event, and discuss appropriate tactics for the best performance: e.g. positioning of players.	Kim et al. (2022), Richlan et al (2023), Noury et al. (2023)
Pressure simulation	Environmental pressures, like a stadium full of people, can be simulated in extended reality. Athletes can get used to the feeling of being in such environment and learn mechanisms to decrease the potential negative impact on their performance.	Noury et al. (2022), Stinson and Bowman (2014), Riach (2013), Richlan et al (2023), Noury et al. (2023)
Sport-specific simulation	A sport can be simulated in an extended reality environment to train specific elements, without the regular physical strain or under	Noury et al. (2020), Ono and Ishikawa (2023), Yasumoto (2023), He et al. (2023), Heo and Kim (2021), Geisen et al.

	certain specific conditions.	(2023), Richlan et al (2023), Geisen et al. (2022)
Injury prevention	Injuries can be prevented by doing specific strength exercises, taking care of movements during sports, and other (non-sport) related aspects. After an injury, specific strength exercises can help the athlete rehabilitate and prevent future injuries.	Schuermans et al. (2022), Reneker et al. (2020), Richlan et al (2023)

Each category of performance improvement is now discussed in further detail. These categories have not been defined systematically in the context of extended reality in previous literature. Below, each category is explained in more detail. All sections follow a similar structure, first defining the category, then providing theory, before illustrating its implications for sports, and lastly discussing the benefits and risks.

Cognition

Cognition relates to processes related to processing information, making decisions, and solving problems. In the context of sport this translates to, for example, reaction time (to catch a ball) or deciding which direction to turn based on the positions of the opponents. In a literature review, Noury et al. (2022) conclude that extended reality appears to be a promising tool for developing perceptual-cognitive abilities. Multiple companies (e.g., Strivr, Rezzil, Reflexion) exist that provide XR-based solutions for sports organisations to improve their athletes' cognitive abilities. Rezzil's systems are used by teams in the English Premier League (Cunningham, 2022). A challenge lies in skill transferability, as a research into room searching procedures for police officers found an improvement when using XR in training, but no improvement when testing again afterwards in the real world (Harris et al., 2021). Long-term usage effects and the skill-transfer for the XR-environment to real world scenarios require further research (Noury et al., 2022).

Motor skills

Motor skills refers to developing the mind-muscle connection to execute certain movements, either sport-specific or in general. Extended reality can improve motor skills by practicing specific movements in an immersive environment. Reneker et al. (2020) researched VR interventions in nine different sensorimotor exercises for football players, finding significant training effects for seven exercises after the intervention, but only one exercise with a significant improvement on actual on-field performance. Most extended reality applications that train motor skills use an HMD. Alternatively, Heo and Kim (2021) developed an AR projection system that displays a character to aid in route finding and body positioning for climbing, which positively affects the motor performance of its users. As in much of the literature regarding XR efficacy for sport, it is limited by its scope (focusing on low-precision movements rather than sophistic movements) and more research is needed to substantiate the findings.

The usefulness of extended reality to develop motor skills is not undisputed, as Noury et al. (2023) did not find any performance improvements in this aspect. It can potentially even lead to performance decrease, if users are learning the wrong movement patterns when the representativeness is too low (Noury et al. 2022). When using XR to train motor skills, caution should be taken in where it is implemented. Noury et al. (2022) suggest using the technology for actions requiring low haptic feedback (e.g. blocking a ball) rather than high haptic feedback (e.g. throwing a ball).

Real-time feedback

Feedback is a broad concept, but in this context it refers to feedback on the movements of athletes. This is often done through coaches or by video recordings, however, it is found that providing feedback in real-time improves performance more (Geisen et al., 2024). Feedback can be provided as self-motion perception, direct actual/target value comparisons, and specific feedback on motions (Geisen & Klat, 2021). In a review of literature regarding using XR as a tool for real-time feedback in sports, Geisen and Klat (2021) discuss its relevance. They pose that AR can be used to project additional information and feedback on motion in the real world, whereas VR can be used to train in a virtual (competition) environment. MR combines both and allows for interaction with physical objects in a digital environment (Geisen & Klat, 2021). Geisen et al. (2024) found that incorporating an XR system to provide real-time feedback significantly improved users' golf putting performance. Whereas Lee et al. (2023) research the usability of a smart-mirror system to provide feedback on people's movement during exercise, Orlandi et al. (2023) have developed an AR-system in which a virtual coach is augmented into people's living room. The coach illustrates a movement, and the person can walk around this digital character from all angles to see how to imitate that specific movement. This illustrates the multitude of possibilities for using XR to provide feedback. In order to receive feedback in real-time, the athlete must use it during exercise. This provides some limitations, as e.g. running with VR-goggles that obscure vision pose a risk to its user (Geisen & Klat, 2021). Being completely immersed in a digital environment while training can also cause motion-sickness (Geisen & Klat, 2021). Geisen and Klat (2021) pose that these limitations can be overcome and the benefits using extended reality for generating feedback are larger than its drawbacks.

Tactical analysis

Tactics here refers to decision-making at a larger scale. It, for example, considers the positioning of players on a football field, or the strategy used in a cycling race to weaken the competition. Often, these analyses are done after a competition to make better and/or faster decisions in the future. The usage of extended reality allows for immersive analyses of scenarios. Koutitas et al. (2019) found that using extended reality yielded better results in training first responders than, for instance, by using a PowerPoint presentation. XR programmers who work in the field of sports underline the strength of extended reality for tactical analyses (Bourhim & Labti, 2023). Building on this finding, immersive environments can be created for sports, like Kim et al. (2022) have done for football. Players and coaches can walk on a football field and see a digital playing scenario, which they can then analyse to improve their tactics. The company 'Beyond Sports' provides its customers with solutions to track and visualize player movements, which can be used for the purpose of tactical analysis. There are no risks to using extended reality for tactical analysis discussed in the literature. A drawback might be high costs for developing the applications, as these should be highly customisable for different scenarios.

Pressure simulation

In elite sports, performance is often under high-pressure conditions. Winning the event itself brings a pressure with it, thus is further enhanced by for example large crowds in a stadium. Pressure simulation refers to putting the athlete in a situation where they perceive similar pressure, in order for them to better handle this. In psychology, extended reality has already been used to mimic specific scenarios for e.g., PTSD treatment (Noury et al., 2022; Stinson & Bowman, 2014). For some military applications, this approach is successfully implemented as well (Noury et al., 2022). In similar fashion, research has been done into recreating the high-pressure sports environment to induce anxiety in athletes. The athletes are exposed to a high-pressure environment (e.g., the competition stadium with a yelling crowd), then practice performing under such conditions, so that in a real-world scenario the negative impact is reduced (Noury et al., 2022). It is important to have a realistic and believable simulation, as Stinson and Bowman (2014), who developed a goalkeeping simulation to research induced pressure, provide this as a possible explanation for why more experienced goalkeepers had insignificant improvements, but lesser experienced goalkeepers did benefit from the intervention.

Sport-specific simulation

This simulation category refers not to a mental simulation, as in pressure simulation, but to literally mimic a competition or part of a sport. XR provides the user with an immersive environment to simulate sports, which can be an improvement given its high degree of interactivity (Noury et al., 2022). Another advantage of this approach include the ability to practice from many locations, decreased physical load, the flexibility to adapt environmental factors, and the possibility to include a customisable digital opponent (Noury et al., 2022). For example, Geisen et al. (2023) developed an extended reality training program for golf putting, and Noury et al. (2023) an application to simulate playing tennis. An often quoted disadvantage of this approach is the possibility to learn incorrect movement patterns if the extended reality environment does not reflect the real world properly, potentially decreasing the performance of an athlete (Noury et al., 2022). The tennis simulation application developed by Noury et al. (2023) focused specifically on this aspect, finding that is sufficiently representative of the real world. Long term research into performance improvements due to sport-specific simulations are too scarce to make any conclusive comments about its effectiveness.

Injury prevention

Injury prevention consists of the steps taken to prevent an athlete from getting injured, entailing physiotherapy exercises, managing training load, having correct movement patterns, and sufficient rehabilitation. Reneker et al. (2019) research the effectiveness of using VR to train sensorimotor abilities and found a 27% decrease in injury rate. Preventing injuries by using extended reality is related to previous sections: by simulating a sport-specific movement the physical load is reduced, decreasing the probability of injury. By having well-developed cognitive abilities and motor skills, athletes are less likely to make sudden incorrect movements that might cause physical trauma. Extended reality can also be utilised to aid in doing physiotherapy exercises, by providing feedback on an athlete’s movement. This not only results in lower injury rates, but is useful for rehabilitation purposes after an injury as well (Bourhim & Labti, 2023; Schuermans et al., 2022). However, more large-scale research is required to determine whether XR interventions are more effective than traditional methods for injury prevention and rehabilitation (Schuermans et al., 2022).

2.4. Summary

This chapter is based on a systematic literature review of 21 articles. Based on these articles, the fundamental components of this study are explained: the metaverse, XR and its components, and the relevance of these topics for sports performance improvement. The metaverse refers to a digital and immersive world, parallel and interactive to the real world. A key technology that enables the metaverse is XR. There are three types of XR: VR, AR, and MR. VR immerses the user in a digital environment. AR projects a digital layer over real-world elements. MR builds on AR, allowing for an interaction between the digital and physical elements. The chapter continues to analyse current research done into XR applications which are used for sports performance improvement. This culminates in a novel categorisation of XR use cases for sport. Seven distinct categories of performance improvement are identified: cognition, motor skills, real-time feedback, tactical analysis, pressure simulation, sport-specific simulation, and injury prevention. These categories of performance improvement focus on different aspects; from mental to physical, from before to after competition, and from specific to very general. For most categories, more research is required to determine whether extended reality can truly benefit in that specific domain. Especially longitudinal research and studies focusing on skill transferability from the XR setting to a real competition situation are missing from the current experimental studies. The general finding from this explorative literature study is that extended reality is a promising domain for the sports industry, but that further development and research are required to substantiate its importance and effectiveness.

3. Methodology

In Chapter 2, a theoretical foundation for the usage of extended reality in sports was established. This chapter sets the organisational scope of the research and justifies the choice of the framework used to structure the study. Furthermore, the approach of the study is explained. The research is qualitative in nature, and is carried out through a multiple-case study. The topic of XR adoption currently remains largely unexplored, thus an exploratory design is most appropriate to research this topic. Case studies are suitable for studies that are explorative in nature (Yin, 2017). A multiple-case study design is chosen since it allows for ‘replication logic’, where findings from one case are corroborated or contrasted with others, strengthening validity (Yin, 2017). An exploratory design’s purpose is to explore and identify patterns, themes, and insights rather than to test a specific hypothesis (Yin, 2017). The aim of the multiple-case study is to describe how each organisation implements XR individually, and to infer the inhibitors and facilitators of adoption, as described in the introduction, through a comparison of the cases. The multiple-case study is structured around the TOE-framework, whose selection and dimensions are explained in the first sections of this chapter.

The organisations which are involved in the study can be found in Table 3. The case studies are conducted by means of semi-structured interviews, held in the fall of 2024. The interview guideline is attached in Appendix B. Questions are based on the operationalisation of key elements for each of the three dimensions of the TOE-framework (see Figure 7). The interviews are transcribed and afterwards analysed using thematic analysis. The resulting thematic map forms the basis for the discussion. Each case is researched individually, followed by a cross-case analysis in Chapter 5.

3.1. Introducing the TOE-Framework

An appropriate framework must be selected and adapted for the specific context of this research before determining the manner in which the information required for the study is collected and analysed. This research has utilised the TOE-framework. This choice is elaborated upon below. Furthermore, the steps taken to adapt this framework are explained. This culminates in Figure 7, which is a graphical representation of the relevant elements and their relationships in this research.

3.1.1. Organisational Scope

The adoption of XR technologies in sports organisations is part of a broader shift known as digital transformation, which involves integrating digital tools and technologies to enhance organisational processes, decision-making, and overall performance. Digital transformation impacts multiple organisational levels, from operational, day-to-day applications to strategic, long-term shifts in vision and structure. Selecting an appropriate framework requires understanding where XR adoption fits within this spectrum.

Frameworks like the Technology Acceptance Model (TAM) are well-suited for operational-level studies, focusing on day-to-day applications (Davis, 1989). Conversely, the Digital Transformation Framework focuses on strategic-level decisions, addressing fundamental shifts in an organisation’s long-term vision and direction (Hess et al., 2016).

Current research into XR for performance improvement primarily operates at the individual level, mainly concerning specific skills or abilities that can be improved, thus focusing on the athlete-coach relationship. This is an operational-level focus about daily activities with immediate, measurable outcomes (Lloyd, 2011). These studies do not concern the research of XR in general, but focus on a specific application. The choice to adopt and use extended reality is one made at a higher level of decision making. Since XR is currently used and researched as a tool that enhances training and preparation protocols, it is unlikely that this technology will overturn sports organisations’ long-term vision and direction, which would place it at the strategic level of decision-making (Lloyd, 2011).

Instead, XR serves as a tactical tool, bridging day-to-day operations with long-term organisational goals.

This research, therefore, focuses on the tactical level of decision-making, where XR is integrated into training and preparation protocols to achieve broader objectives. The selected framework must reflect this middle-ground approach, addressing both technological opportunities and the organisational and environmental factors influencing XR adoption.

3.1.2. Framework Selection

The scope of this study is set to the tactical layer of decision-making within the organisations. To structure the research, a framework is required that allows for analysis on this organisational level and is suited to the research context. As mentioned previously, the adoption of XR into sports organisations can be viewed as part of the general trend of ever-increasing usage of digital technologies within organisations: digital transformation. Digital transformation is a heavily researched topic. There are various frameworks usable for studies in the context of digital transformation. Combined with the need for a tactical analysis, the Technology Organisation Environment (TOE) framework is a well-suited choice (Abdurrahman et al., 2024; Nguyen et al., 2022).

The TOE-framework is used in numerous papers on VR and AR adoption in organisations and industries (Gao et al., 2023; Kumar et al., 2016; Masood & Egger, 2019; Moorhouse, 2019; Sousa et al., 2023; Zheng et al., 2024). Additionally, it has been used for another technology adoption and utilisation research in sports organisations, in this case, big data (Abeza et al., 2022). For big data adoption studies, the TOE-framework is the most popular (Baig et al., 2019). Since this research sits at the intersection of these past works, researching XR adoption in sports organisations, the usage of the TOE-framework is substantiated. This framework will thus also be used in this paper to structure the research and ensure that the tactical organisational level is attained.

Developed by Tornatzky et al. (1990), the TOE framework explains three dimensions that influence technological innovation adoption: technological context, organisational context, and the environmental context. Technological innovation adoption in this research context refers to how XR is adopted within sports organisations. The framework is generic and the factors that make up each dimension are highly adaptable, making it relevant for many different technological, industrial, and national contexts (Baker, 2012). The generic characteristics of the framework make it suitable for this research specifically, given the explorative nature of the research.

Other frameworks, such as the Technology Acceptance Model (TAM) or the work by Hess et al. (2016) on digital transformation, did not suit the research context. In TAM, the scope is too narrow. It focuses mainly on user acceptance of the technology, not on organisational constraints for adopting a new technology (Davis, 1989). The work by Hess et al. (2016) might be very useful for a future investigation into extended reality adoption, as it considers changes in value creation, organisational structure, and finances. Currently, extended reality is hypothesised to have a too low and narrow impact on the organisation for there to be any changes according to these dimensions. The TOE framework can be adopted such that it includes all relevant aspects of extended reality adoption, and in a way that will also provide meaningful findings even if the impacts of the technology are small.

The application of this framework allows for a comprehensive review of how and why XR is used within sports organisations. The three dimensions are further explained in the sections below. The variables chosen for each dimension are determined by their frequent use in TOE framework research and by a study on big data adoption, which, while focusing on a different technology, employs a research approach similar to that of this study (Baig et al., 2019; Baker, 2012).

Technological context

The technological context refers to technologies that are available to an organisation, including those that are not used. In our research, this dimension is adapted to focus mainly on one specific technology, XR, rather than all technologies available to organisations. The technological context concerns the characteristics of the technology, such as how widely available it is, and how it can be used in organisations (Baker, 2012). The previously found seven categories of XR usage based on the literature review fit into this dimension of the TOE-framework. Additionally, the requirements for implementation and availability of (supporting) technology should be included for a full image of the technological context. This culminates in the perceived benefits and perceived barriers of implementing the technology. These two factors have been used in previous research as well (Baker, 2012).

Organisational context

The characteristics and availability of resources of an organisation make up the organisational context. Naturally, sufficient resources should be available for new technologies to be tested and implemented. Firm characteristics are composed of multiple elements, such as size, structure, and culture, and have a more complex relationship with innovation decision-making (Baker, 2012). Organic firms are likely to adopt new technologies faster than mechanistic firms, given their fluid responsibilities and emphasis on teams and lateral communication (Baker, 2012). In the context of sports organisations, the type of sport that the organisation performs in is also relevant. Top management support and the presence of innovation champions are used in previous research as important organisational factors (Baker, 2012). Chanias and Hess (2016) further substantiate the importance of top management support for digital transformation initiatives.

Environmental context

The environmental context considers the industry, in this case, the performance sports industry. The involvement of technology service providers and the regulatory environment are also included. Competitive industries tend to be more innovative with regard to technological adoptions (Baker, 2012). The presence of supporting infrastructure to implement and use a technology, such as soft- or hardware developers and consultants, also has a positive effect on the degree of innovativeness (Rees et al., 1984). In the context of XR usage in the sports industry, this supporting infrastructure is referred to as the technology producers (see Figure 6 in Chapter 2). Regulatory bodies can both boost and hinder innovation (Baker, 2012). By constraining industries, such as extensive procedures mandated by the International Football Association Board (IFAB, for American Football) before implementing new equipment (such as helmets) innovation is slowed down. In other instances, such as FIFA introducing the Video Assistant Referee (VAR) in football, innovation is promoted by boosting development in video technology and data analytics.

Figure 7 illustrates how each dimension of the TOE framework, split into three dimensions, culminates into the facilitators and inhibitors, which in turn influence the adoption of a new technology. The variable selection is explained above. Adapting the variables for each dimension to the specific context of the research is an important step in TOE-framework usage (Baker, 2012). The elements of each dimension, such as ‘resource availability’, are the factors that are used further in the research and are operationalised in Section 3.3. The figure itself is based on work by Baker (2012) and Abeza et al. (2022), and then adapted to suit the context of this study specifically. The structure of the figure is adjusted to improve the clarity of the relationships between the elements. The framework in Baker (2012) and Abeza et al. (2022) depicted all relationships with solid lines. The adapted TOE-framework in Figure 7 depicts the relationship between the TOE-dimensions and the facilitators and inhibitors by means of a dotted line. This is done to underline their function as input, and not as them having a causal relationship. The latter is the case for the facilitators and inhibitors towards the adoption and utilisation of innovation, hence this relationship is depicted as a solid line.

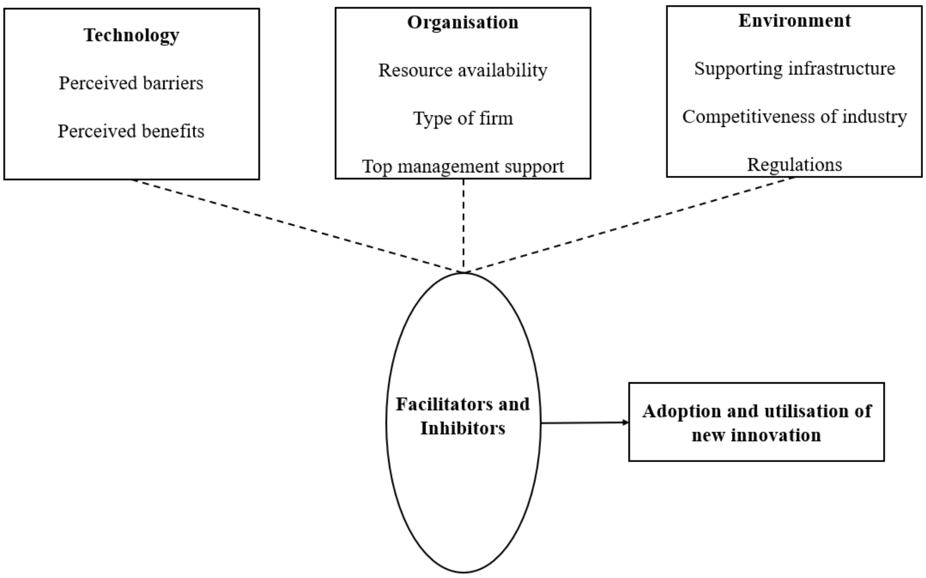

Figure 7. TOE-Framework, adapted from (Baker, 2012; Abeza et al., 2022).

The remainder of this chapter explains the case selection process, and the data collection and analysis approaches. The data which is collected for this research is based on the variables depicted in Figure 7.

3.2. Case Selection

This study comprises of a research of three cases. The small number of cases allows for rich detail in analysis, balancing sufficient depth and complexity of the research (Yin, 2017). As the topic of the research is the implementation process and consequent usage of XR, the unit of analysis is the sports organisation as a whole. Analysing the entire organisation is common for comparative case studies on the topics of technology implementation and digital transformation (Hess et al., 2007; Kyratsis et al., 2012). The sports organisations that are selected for the study are key organisations in their respective sport(s), or hold an important role as governing body. As this research is exploratory, heterogenous sports organisations have been selected to gain insights from multiple perspectives; they are either non-profit or commercial, and focus on a specific sport or on multiple different sports. These cases have been selected by means of purposive sampling, as they are prominent organisations with substantial reach, making them likely to provide rich information. To protect the sensitive information shared by the organisations, including details about their internal processes, testing methods, and extent of extended reality usage, the organisations have been anonymised. They are described in Chapter 4.

In addition to selecting prominent sports organisations for participation, a preliminary overview of technology producers is made and attached in Table 11 in Appendix A. Indicative lists of readily available applications for sports organisations in the Meta Quest library are summarised and available in Table 12 in Appendix A.

Table 3. Organisations Selected for Case Studies

Organisation	Type	Focus
A	Non-profit	Multiple sports
B	Commercial	Multiple sports
C	Non-profit	Single sport

3.3. Operationalisation

The factors that are researched in accordance with the TOE-framework are depicted in Figure 7. Below a more detailed explanation of how each factor is measured is provided. In Table 4, these measures are summarised. Based on these operationalisations the interview guide is made, which is attached in Appendix B.

3.3.1. Technological Context

The technological dimension of XR adoption in sports organisations is explored through three key variables: the perceived barriers to XR usage, the perceived benefits of XR usage, and the extent of XR application usage.

The perceived barriers to XR usage highlight the challenges organisations face when adopting XR technology. Measured by statements made by the participants that reflect a negative sentiment towards XR usage, or problems with adoption of the technology. When there are a few and easily overcomable barriers mentioned, the perceived barriers are rated as low. When there are many barriers mentioned that hinder adoption, or at least one barrier that fully inhibits XR adoption, this indicates high barriers to XR usage.

Conversely, the perceived benefits of XR usage reflect participants' positive views on XR usage or organisational elements that facilitate XR adoption. These benefits are rated as low if they are few and have minimal impact, moderate if they are notable but not transformative, and high if they are numerous and significantly enhance adoption and usage.

Finally, XR application usage examines how organisations implement XR technology across various categories of sports performance improvement. This involves cross-referencing the categories outlined in Table 2 of Chapter 2 with the applications currently in use. Categories are marked as present when relevant applications are adopted, or not present when no applications align with the category.

3.3.2. Organisational Context

The organisational dimension of XR adoption is assessed through five variables, each highlighting a different aspect of an organisation's internal environment. These include resource availability, the type of firm, top management support, and technological innovation policies.

Resource availability is considered a crucial factor, comprising of two types: financial and time availability. Financial availability reflects the budget allocated for XR development and adoption. Organisations with sufficient financial resources can support XR adoption without constraints, whereas those with limited budgets may face restrictions on the scale or frequency of projects. Insufficient budgets hinder or entirely prevent XR projects. Similarly, time availability considers the extent to which employees can dedicate time to XR projects. Organisations where employees have sufficient time can actively pursue XR adoption. When employees are constrained in the amount of time they can spend on XR projects by competing priorities, this can be categorised as either limited or insufficient, depending on the degree of the constraint.

The type of firm, as conceptualised by Burns and Stalker (1961), is described as either mechanistic or organic. This classification is based on three sub-dimensions: formalisation, centralisation, and complexity. Firms with low formalisation operate with few documented policies, whereas those with high formalisation have extensive procedural guidelines. Similarly, centralisation varies from low, where employees have autonomy, to high, where decision-making is tightly controlled by management. Finally, complexity refers to the organisation's structure, ranging from low, with minimal specialised roles and layers of management, to high, with numerous specialised roles and a hierarchical structure.

Top management support evaluates the involvement and prioritisation of XR initiatives by leadership. Organisations with extensive support benefit from active involvement and a strong focus on XR adoption, while those with limited or no support may struggle to prioritise such projects.

Finally, technological innovation policies assess the clarity and existence of formal guidelines for XR adoption. Organisations with clear policies can strategically guide XR usage, while those with limited or non-existent policies may face inconsistencies or a lack of direction in adoption efforts.

3.3.3. Environmental Context

The environmental context of XR adoption is operationalised through three key variables: supporting infrastructure, industry competitiveness, and regulatory factors.

Supporting infrastructure is measured by the perceived presence and support of external organisations that help with the adoption of XR technologies. Both the number and variation in types of external organisations that support with XR adoption, as well as the closeness in the relationships between the external organisation and the participating organisation are included in this measure. Varied types of external organisations refer to disparity in partners e.g., knowledge institutions, local governments, and private companies. As illustrated in Figure 6 in Chapter 2, this includes the technological developers and the application developers. The number of partners is rated as low when only a few, similar external organisations are involved, moderate when there are few varied or many similar external organisations, and high when a large and diverse range of organisations actively supports XR adoption. Similarly, the closeness of these partnerships is evaluated, with low reflecting distant and transactional relationships, moderate indicating somewhat collaborative but not deeply integrated partnerships, and high representing close, collaborative relationships that foster innovation and development.

Industry competitiveness is measured by the level of perceived pressure to innovate in order to maintain or improve organisational performance. In the context of sports organisations, this pressure extends beyond market share to include athletic performance, which directly impacts competitiveness. The competitiveness of the industry is rated as low when there is little to no pressure to innovate, moderate when some innovation is necessary to keep up with competitors or improve performance, and high when significant and ongoing innovation is required to remain competitive or achieve superior results.

Finally, regulatory factors are examined to understand the legal and internal organisational constraints affecting XR adoption. Government regulations are assessed based on the level of legal requirements imposed by local or national authorities, with low indicating minimal legal restrictions, moderate reflecting manageable requirements, and high meaning significant regulatory hurdles affecting XR adoption. Similarly, internal policies are evaluated based on their impact on XR adoption, with low indicating minimal internal regulations, moderate reflecting the presence of some manageable internal policies, and high representing well-defined organisational regulations that significantly influence the adoption process.

Table 4. Operationalisation of Metrics

	Low	Moderate	High
Technology			
Perceived barriers	Few and easily overcome able barriers mentioned.	Some significant barriers.	Many barriers or one that fully inhibits adoption.
Perceived benefits	Few benefits mentioned, minor in impact.	Some noticeable benefits but not transformative impact.	Many benefits, significant impact on XR adoption.
Organisation			
Financial availability	Budget inadequate to initiate or sustain projects.	Budget allows some projects but is restrictive.	Sufficient budget for projects.
Time availability	Employees have minimal or no time for XR projects.	Some time is available for XR projects but constrained.	Adequate time for XR projects.
Formalisation	Few documented procedures or policies.	Some documented policies, informal processes remain.	Extensive documentation.
Centralisation	Employees have significant autonomy.	Decision-making shared between employees and management.	Most decisions made by higher management.
Complexity	Few specialised roles, minimal management layers.	Some specialised roles, moderate management layers.	Many specialised roles and many management layers.
Top management support	No interest or involvement in XR adoption.	Occasional support, not a priority.	Active involvement, strong prioritisation.
Technological innovation policies	No policies exist regarding XR adoption or usage.	Some vague or inconsistently applied policies.	Well-defined, consistently applied policies.
Environment			
Number of partners	Few external organisations provide support for XR projects.	Few varied or many similar organisations to provide support.	Many and varied external organisations actively involved in XR projects.
Closeness of partners	Relationships are distant and transactional.	Relationships are somewhat collaborative but not deeply integrated.	Collaborative partnerships with external organisations.
Competitiveness of industry	Little pressure to innovate or improve performance.	Moderate pressure to maintain competitiveness.	Strong pressure to innovate for athletic or business success.
Government regulations	Minimal or no regulatory pressures from government.	Some regulatory considerations.	Strong regulatory requirements hindering XR adoption.
Internal policies	Minimal or no internal regulations.	Moderate internal policies exist, limited impact on XR projects.	Extensive internal regulations impacting XR adoption.

By clearly defining how each metric is measured and evaluated, it is transparent how the collected data is turned into the results.

3.4. Data Collection

To conduct the case study research, semi-structured interviews with employees within the organisations are held. The interviewed employees are actively involved with the XR applications within the organisation. The semi-structured format was chosen for its flexibility, allowing participants to elaborate on context-specific insights while ensuring coverage of key themes aligned with the study's objectives (Yin, 2017). This method is particularly well-suited for exploratory research, enabling the collection of rich, qualitative data on complex phenomena like XR implementation.

The interviews lasted an average of 55:51 minutes (with a standard deviation σ = 4:30), and one interview per organisation was used to collect the relevant information. A single interview was deemed sufficient to gather the required data due to the exploratory nature of the study and the structured approach used during interviews, which ensured comprehensive coverage of the research topics. The decision was also motivated by participant availability. Saturation was reached within the single interview for each organisation, as no significant new insights emerged from additional questions. For one organisation (B) a secondary 10-minute interview was conducted for clarification purposes, but this was not required for the other organisations.

The selected organisations are situated in two different countries in Europe. Interviews are held in the language that the participant feels the most comfortable with. The transcripts of interviews held in the local language are automatically translated to English using, deepL, a translator. The revised transcriptions are manually checked with regard to correct translation and meaning. This process reflects Yin's (2017) emphasis on maintaining data integrity in case study research. Additional information from open sources on the internet, e.g., organisations' websites, are used for a holistic image of the organisation. This aligns with Yin's (2017) recommendation to use multiple data sources, triangulating findings and reducing the risk of bias.

3.5. Data Analysis

The data collected from the interviews were analysed using thematic analysis, a method widely recognized for its flexibility in identifying and reporting patterns (themes) within qualitative data (Braun & Clarke, 2006). Thematic analysis allows for a rich, detailed, and nuanced account of the data, making it suitable for exploring complex issues such as the implementation of extended reality (XR) in sports organisations. This method enables the researcher to go beyond surface-level observations and engage with deeper, more latent meanings present in the data. The flexibility of this method makes it more suitable than e.g., the Gioia-methodology, which is more rigid in its analysis process (Gioia et al., 2012). The seminal work of Braun and Clark (2006) is used as a guide in the analysis process. The phases of analysis are displayed in the Table 5.

Thematic analysis involves a systematic and iterative process of coding and theme development. The analysis began with a thorough familiarisation with the data, where interview transcripts were read and re-read to identify initial ideas related to the three dimensions of the TOE-framework: technology, organisation, and environment (Braun & Clarke, 2006). This is the foundation for generating initial codes, which are short labels applied to segments of data that appear relevant to the research question. The open-source program Taguette[13] is used to organise the coding process.

These initial codes are then used to form broader patterns or themes. Analysing the transcripts to find codes and then form themes is an iterative process, which is repeated until different versions are exhausted and the most complete themes are found. The initial codes are found through an inductive process, ensuring the themes emerge from the data. With the exception of the structure typology, the

[13] https://www.taguette.org/

themes are not constrained to a pre-existing framework. The themes are structured around the dimensions of the TOE-framework, but in a flexible and adaptable way. The codes and themes result in a thematic map (see Figure 8 in Chapter 4), which is used as a basis for the discussion of the paper.

Table 5. Thematic Analysis Process (from Braun & Clark, 2006)

Phase		Description of the process
1.	Familiarising yourself with your data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2.	Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3.	Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4.	Reviewing themes:	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5.	Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6.	Producing the report:	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a report of the analysis.

The emerging themes and initial codes are used to describe each sports organisation individually, and also to form a comparative analysis. The comparative analysis focuses on similarities and differences between the organisations, where underlying explanations are discussed. The thematic map, along with findings for the sports organisations and the comparison, are presented in Chapter 4.

3.6. Summary

To determine the appropriate framework for the study, first, the organisational level at which decisions regarding XR adoption are made must be determined. XR is currently used as a tool to reach strategic goals, but does not overturn or change the general vision of sports organisations. The bridge between the day-to-day usage of XR and strategic goal-setting is at the tactical level, which is thus the organisational level this study will focus on. Numerous frameworks exist that can be utilised for technology adoption studies. However, the tactical level and the explorative nature of the study require a specialised framework. Frequently used frameworks like TAM or the Digital Transformation Framework either have a too narrow scope or expect the technology to have a fundamental impact on the organisation (Davis, 1989; Hess et al., 2016). The TOE-framework, developed by Tornatzky et al. (1990), overcomes these issues. The framework researches innovation adoption through three dimensions: technology, organisation, and environment. This provides a holistic analysis of the innovation adoption. Furthermore, the factors that make up the dimensions are highly flexible and can be adapted to the study's specific needs. The TOE-framework is used in similar studies, both for VR and AR adoption in a variety of industries (Moorhouse, 2019; Gao et al., 2023; Zheng et al., 2024; Sousa et al., 2023; Kumar et al., 2016; Masood & Egger, 2019), as for a big data adoption study within the sports industry (Abeza et al., 2022). In this study, the technology dimension is measured through the perceived barriers and perceived benefits of XR. The organisation dimension is operationalised by analysing the resource availability, type of the firm, and presence of top management support. Lastly, the environmental dimension is analysed through the supporting infrastructure, the competitiveness of the industry, and regulations. This is summarised in Figure 7, which is the adapted TOE-framework that will be used in this study.

For this study, a multiple-case study methodology is used. The goal of this approach is to describe how each organisation implements XR individually and discover similarities and differences through a cross-case analysis, based on the aforementioned TOE-framework. Three prominent sports organisations are selected, who each have a different perspective (see Table 3). This provides the research with different insights. The selected organisations are anonymised. The factors that make up each dimensions of the TOE-framework are operationalised (see Figure 7 from Section 3.1), to illustrate how they are measured and used to identify the facilitators and inhibitors of XR adoption. Data is collected from the participating organisations by means of semi-structured interviews. A single interview per organisation is conducted, with an average duration of just under an hour. The interview transcripts are analysed according to the thematic analysis approach, which is depicted in Table 5. This approach is flexible, allowing for the finding of latent meaning within the data. The results of this analysis culminated in a thematic map, see Figure 8 in Chapter 4. The individual case results are depicted in Chapter 4 as well.

4. Results

In this chapter, a description of each sports organisation individually is provided. The individual case descriptions are structured along the TOE-dimensions and their relevant metrics, see Figure 7 in Chapter 3. In the discussion the findings are expanded upon, as reasons for similarities and/or differences are discussed.

4.1. Organisation A

Organisation A is the national governing body for sports in its country, responsible for overseeing and supporting both elite and recreational sports. Its mission is to advance sports development nationwide. Among other activities, it provides support to high-performance sports facilities and training centres.

Technology

Organisation A is currently pursuing three pillars of innovation leading up to the 2028 Olympics: *"sensory technology, artificial intelligence, AI, and the third is extended reality"*. They consider these as emerging technologies that the organisations feels they are currently not using enough. Extended reality is quoted to be the least focused on of these three pillars: *"I have to be honest that VR is the neglected child […] because there are many more technologies that are already very easy or more proven to be applicable where people already get more out of it. So because VR is still in its infancy, it is quickly being neglected in terms of time."* The current focus is mainly on virtual reality on the extended reality spectrum (see Figure 3 in Chapter 2). The technology is not yet widely accepted and used in Organisation A, but multiple pilot projects have been run. The organisation appears to be hopeful about the future possibilities of extended reality.

Organisation A has used extended reality in multiple projects, among which for archery, snowboarding, and one for general relaxation protocols surrounding the 2024 Olympics. The archery project simulated the 2024 Olympics stage, and could be manipulated to train the archers for competition specific environmental factors, such as a screaming crowd, or an opposing player who is outscoring the archer. For snowboarding, the athletes used a 360-degree camera to record their run. They could later analyse their performance using virtual reality glasses, which helped them visualize their run. The general relaxation project allowed athletes to immersive themselves in a calming environment, such as a beach, to calm down after a competition. This project is quoted to be a large success, with there being *"a run on the VR-glasses"* by the athletes attending the 2024 Olympics. These projects fall into the categories for performance improvement by using XR as identified in the literature review, and are summarised in Table 6 in Chapter 5.

The main barriers with implementing extended reality are related to the development of properly functioning applications and convincing both management, to free up budget and time, as well as the users (coaches and athletes that will actually use the technology). For both managers and coaches, scepticism can be explained by the lack of experience in using extended reality. After trying out VR-glasses, many of the initial concerns about its relevance are taken away. The development of applications is perceived as a hinderance given its required time and expertise. The limited knowledge of managers and coaches appears to be problematic again: once convinced of the relevance of extended reality they might have unrealistic expectations of what the technology can do. The programming capabilities then do not match the desired functionalities: *"Of course, programming is a lot of work. […] Then you have to say: sorry, but that is not possible yet."*. This also translates to the domains Organisation A is currently using extended reality for: processes that do not entail movement in the immersive environment. This is said to be too difficult to develop well at the moment, since the changes in movement are very small and specific at top-level sports.

Developing applications that allow for the training of these specific movements, perhaps paired with sensor technology or Electromyography (EMG) to get a complete image of the neuromuscular movements of athletes, is one of the future directions Organisation A would like to delve into. There are also ideas concerning improving sports intelligence, where multiple (adaptable) scenarios are depicted and an athlete should choose the most appropriate one.

Organisation

The role of Organisation A is important for the competitiveness of the country it represents in international events, as it supports athletes and federations. To do so, they have structured their organisation along functional departments, such as nutrition or technology. The technology aspect is most relevant to the implementation of extended reality. This department consists of three people, of which one holds an overseeing and policy-focused function and the two others have their own respective responsibilities, focusing on specific technological domains. The management is in general supportive of extended reality, as is reflected in the three innovation pillars Organisation A is pursuing.

The most common implementation process for XR-application entails one of the employees in the technology department finding a specific application they think is valuable. They then discuss this with the head of the technology department, after which they contact the respective expert in the area of the application (e.g., psychology) and the performance manager (who is responsible for a cluster of sports). Together with the performance manager, the specific federation is then contacted to set up a trial project. A written and formal plan is submitted to the head of the top sport division, who has to sign off on the project. Sometimes the process is reversed: a federation contacts the technology department with a technical innovation they found, and requests support for its development and implementation.

Despite the three-people team working on the selection and implementation of innovative technologies, the time available is still perceived to be limited for discovering and developing possibilities that come with extended reality. The time and budget constraints are most obvious for the software development aspect of implementing extended reality. This development process is expensive, and might even lead to the cancellation of projects: *"The hours of programming that go into it are of course very expensive. […] You are soon at €25,000, and then people say: never mind then."*. Financial constraints are thus present, at both Organisation A itself and the federations that they aim to support. While the first needs to make considerations with which technology to focus on, the latter faces an arguably more difficult decision: *"whether you buy a coach or a VR headset […] that's a trade-off"*.

The organisation is structured organically, with informal communication and a low complexity. Employees all work in the same office space, facilitating the exchange of information, both horizontally and vertically as *"they [management] just walk around here"*. Centralisation is medium, as employees have autonomy over their specific work tasks but the general outline is set out by overarching policy.

Environment

To develop XR-applications, Organisation A collaborates with knowledge institutions and private companies. The knowledge institutions, such as research universities, help to develop applications and conduct research to measure effects. For these projects, government subsidies are used as a means of financing. The private companies offer ready-made applications, which are used either off-the-shelf or are adapted to Organisation A's specific requirements. The collaboration with private companies is said to be not very profitable for those organisations, and is thus mainly done out of enthusiasm for supporting the national sports: *"[…] but purely from passion, because financially and business-wise they don't get that much out of it"*. Organisation A attempts to create a deeper relationship than just that of supplier and customer, seeking a connection and aiming to collaborate rather than just purchase a product. Both types of stakeholders are said to be very skilled and involved, however, each comes with a disadvantage too. The knowledge institutions partnerships do not cost money, but projects often take longer than planned. The private sector works faster, but has a commercial interest and is thus more expensive.

Organisation A perceives there to be an external pressure to adopt new technologies in order to remain competitive, stating that it is crucial to stay on par with the competition. The majority of the pressure for technological innovation is, however, self-imposed, as the interviewee indicated: *"You want to be at the forefront: we consider ourselves an innovative country."*.

There are currently no regulations inhibiting the implementation of extended reality. The only regulatory issue to consider is the storage of data, as this needs to be done safely and securely.

4.2. Organisation B

Organisation B is a global company with a strong presence in the sports industry as part of its broader brand strategy. To support the approximately 1,000 athletes it collaborates with, the organisation has established Athlete Performance Centres (APCs), located in Europe and North America. These centres offer services such as injury rehabilitation and regular performance evaluations. Athletes typically visit these centres bi-annually for a week at a time and are supported by a dedicated performance team, which may include specialists such as nutritionists, mental performance experts, strength-and-conditioning coaches, and doctors. Each specialist typically works with four to six athletes at a time. This study focuses on an APC located in Europe, where the interviewee is based.

Technology

Organisation B is still exploring the possibilities, capabilities, and limitations of extended reality. They have run some projects, and are in collaboration with a software developer for XR in sports, but XR usage is still in an experimental phase: *"We are actually currently testing a lot of these tools out. So I can't tell you that we have loads of experience with it, but I can just tell you what we're trying to do"*. The projects that are run focus on virtual reality. The most used application lies in the mental performance domain, as it is used to improve cognitive function (e.g., reaction time) or used to help athletes relax, by providing a meditative context: *"We can create a real, immersive meditative environment. And we really encourage athletes to get deep rest because it's something that they're not really getting at all, ever"*. The cognitive trainings have two goals, 1) to improve a specific cognitive component, and 2) to initiate movement in injured athletes. Another area that Organisation B tries to use virtual reality for is in the rehabilitation process, again focusing on the mental aspect. After, for example, a cyclist has crashed, they might utilise virtual reality to place the cyclist back in that situation, to decrease the fear the athlete might have. Reliving these situations in a virtual environment is of course much safer, and this is relevant to Organisation B given their tendency to support athlete participating in extreme sports.

Any extended reality applications are said to be a final resort, as the modus operandi focuses on *"human before technology"*, and a dependence on technologies should be prevented. The meditative environment described before is exemplary of this: *"If you want someone to be able to achieve that [deep rest] on a fundamental level, they have to be able to face their own thoughts, their own emotions, and process that. And if they don't do that, they're just adding on a virtual reality headset and blocking it all out. And then when they take it off, it's still there"*. Another explanation for the limited usage and experimentation with extended reality is the limited time available with an athlete: *"The athlete stays for one week, when the time is there to maybe use VR they already leave again"*. Barriers that relate specifically to extended reality are the development of appropriate applications and the lack of expertise regarding the technology. Building the immersive environments in a way that is suitable for the athletes is another hinderance for the implementation: *"We face a lot of barriers with […] creating an environment within the virtual reality that simulates the pressure. I think that's kind of where we're struggling at the moment because it is a lot of extra effort on our behalf"*.

In the future, the APC would like to use extended reality more often for visualization purposes as well, helping athletes build mind-muscle connection. Additionally, they want to expand their support in athletes' pre-performance routines, by e.g., developing an immersive environment that replicates the surroundings of the competition.

Organisation

The APC is structured as an independent unit within the general organisation of Organisation B. It is structured along functional departments, with e.g., mental performance, nutrition, and strength & conditioning. Each department has a head, and these department heads are led by the global performance director. The highest position is that of centre manager. While the employees have to adhere to Organisation B's guidelines, they have high degrees of autonomy in the way they perform their jobs: *"You bring your own individual approach and philosophy into your practise as a mental performance specialist, but of course you align with the global philosophy of Organisation B"*. Communication between employees of different departments is a mix of formal and informal. During normal work activities, information is shared rather informally. When having meetings about particular athletes and how to improve their performance, communication becomes more structured and formal. Regarding extended reality, the information that is shared between departments is rather limited. An extensive project at the strength & conditioning department was only known by name by the interviewee (a mental performance specialist), not in any detail.

The APC currently has no policy regarding the usage of extended reality. Rather, they only use it when deemed necessary, and then adapt how they will use it to the specific athlete it concerns: *"It is very much individualised what we're trying to approach with it […] it's so experimental: we don't have any structures in place […]. It's more so: we want to try this, are you interested? And then explain what it is, what we're trying to do, and then try it".* Besides the aforementioned collaboration with the prominent application developer, Organisation B mainly focuses on existing applications to reduce costs. From an extensive list of possibly useful apps, they will select a few to purchase and trial. This list was created by an intern, and focused on sport psychology. Once more, the departments appear to limitedly share their knowledge, as the other functions are not included in the research. The decision to research further into existing extended reality applications is made within the mental performance department, there was no push or support from higher management to venture into this technology direction.

Resource availability plays a role in the degree opportunities of extended reality are researched. As stated before, an intern created the overview of existing applications. This indicates that the regular employees do not have sufficient time for such research besides their main tasks, and there is no specific department focusing on technology/innovation: *"it [researching XR opportunities] only recently got brought back up to the forefront, and that's when we hired an intern".* The costs of extended reality limit further development and customization of applications: *"It's a huge expense and huge effort to try to develop something with a third party".*

Environment

The limited usage of extended reality within Organisation B's APC means they have not build up an extensive network of supporting infrastructure for the development and implementation of extended reality. They have constructed an extensive overview of existing applications, that they might test and then contact the developer to customize where needed. The exception to this is an extensive multi-year individualised project with one of the major XR-developers within the sports industry. They have not collaborated with knowledge institutions to develop and/or integrate extended reality into their processes.

The unique set-up of the Organisation B APC has as a consequence that there is no competitive pressure perceived to use and integrate extended reality, or any technology, into their processes. They feel to be the leader in the industry, and even help smaller performance centres *"[…] we support a lot of other mental performance teams, we're quite collaborative in that way"*. The only pressure that is perceived is self-imposed and internal: *"Do I feel pressure to perform and do my best? Yeah, of course, because I want to help the athletes the best way possible and show up for our team and what we stand for"*.

Organisation B perceives there to be no regulatory reasons to prevent the implementation of extended reality into their regiment. The only concern lies in confidentiality and data storage, which are more general concerns with the increasing digitization of the (processes within the) organisation.

4.3. Organisation C

Organisation C is the national federation for two racket sports, supporting athletes and clubs at both elite and amateur levels. Its mission is to promote participation in these sports, regardless of skill level, with an emphasis on keeping the activity affordable. In its 2024–2028 strategic plan, the organisation highlights the importance of technology and digitalisation in sports, including the potential to connect people within virtual environments.

Technology

Organisation C currently uses extended reality mainly for improving the viewing behaviour of athletes. They developed a VR application in which *"you see the server on the other side of the net, who hits a serve and you as the returner have to predict where the ball will go".* This application is developed such that a lot of data can be collected, making it valuable for research purposes as well. A similar application is used which is developed by a commercial party [anonymised partner name]. This application can also be used for other situations, such as practicing double play. The Sense Arena has more usability for different situations to practice, their own environment is much better suited for research and manipulation of specific elements. Virtual reality is also used by Organisation C for fan engagement at events, by having a practice set-up for people to use. This use case is promising for commercial purposes for sports organisations, but out of scope of this research, as it does not improve athlete performance.

Organisation C struggles to give extended reality a more permanent place in coaches and athletes their training schedule: *"I'm trying to give it a more permanent place in the training, instead of it only being used when someone happens to need it"*. A limitation of the virtual reality applications currently on the market is the accuracy of the physics, especially for higher level players. The animation of the rotation of the ball does not always accurately represent reality. That is why they currently recommend to *"use those virtual reality games very well for training viewing behaviour or anticipation, but you should not use it for teaching the frontend or a backend".* Coaches and players are also sceptical, since they are unfamiliar with the technology and wonder about the skill transferability from the virtual environment to real performance. Regarding the hardware available on the market, Organisation C is positive, except for a minor criticism about the sharpness of the display.

In the future, Organisation C envisions developing specific environments to simulate competitions, such as the Wimbledon stadium. A desired future augmented reality application is to be able to have direct feedback for coaches and athletes, e.g., by having the speed, type of spin, and heartrate displayed in the corner of the glasses using augmented reality.

Organisation

Resources are limited, especially time. The person pushing the implementation of extended reality is the head of sport science, who also has many other tasks: *"I am head of sports science and also very much involved with innovation, so they are actually two hats that can easily be carried out by one person, but in an ideal world you would perhaps separate them"*. Organisation C strives to *"continuously work on scientific knowledge, implementing and applying it in our programs […] also* *with performance improvement in a data-driven way".* Extended reality is just one piece of that puzzle, complicating its development. Budget limitations also play a role, as the interviewee believes that scepticism among coaches and players can be resolved by letting them try VR headsets, but it is too expensive to do on a large scale: *"[...] people are willing to try a VR headset and then do something with it yourself, but that is quite expensive and quite a challenge".* If a project is deemed promising, the organisation is willing to invest substantially. They do not have a fixed budget for innovation, financial decisions for the development of innovations are done on a project-by-project basis.

Organisation C is rather informal in communication, as *"everyone knows how to find us".* There are four layers of management, each department has a head, followed by a board, and a board of directors. The work activities are decentralized, and autonomy is high: *"In a coaching way, he [supervisor] gives leadership, so to speak. Instead of dictating very much what to do exactly. That is also why I get and experience a lot of freedom".* The organisation sometimes encounters issues due to the high autonomy and informal way of working, as some steps are not going through the right management layers: *"On some fronts, that happens too informally, because managers find that something has to go through them".*

The management of Organisation C is supportive of initiatives, but there is no general strategy or policy clearly driving the development of extended reality: *"how can we use this [extended reality] more from a strategic level and policy level so that it contributes to the goals that we have".* Because of this, many applications are introduced and tried sporadically. A clearer strategy or policy on (technological) innovation would help to streamline related work-activities: *"Now it is still a bit too much bottom-up. We are, within the departments themselves, busy with what do we find important and how are we going to do that? [...] I would actually like to turn it around: [...] What is our strategy, what are our goals and how can we work on innovations from there to meet those?"* To improve this (internal) criticism, Organisation C wants to restructure and include a stronger pillar for innovation management and strategy. Currently, innovation takes places in the departments themselves and the department of sport science is pioneering new technologies. This approach has advantages and disadvantages: *"It's partly a strength, because every department is working on it. But the disadvantage is that we don't have people that very specific work only on innovation, it's just part of people their work".*

Environment

Organisation C works closely with knowledge institutions, such as research universities, to develop applications and conduct research. This collaboration goes both ways: *"If we have questions, we know where to find him [anonymised professor at research university], but they also know where to find us if they have certain things that they think, maybe this is interesting for you".* The organisation is also supported by the overarching national governing body for sports, which helps with the development and integration of new technologies. Additionally, Organisation C receives funding from the government through sports innovator. Sports innovator is a collaborative network with the Ministry of Health, Welfare and Sport, universities, sports organisations, and the private sector. They aim to develop innovations to get more people active, and to win gold medals at the Olympics. Inspired by this working method, Organisation C uses a similar approach for more of their innovation projects: *"we also try to now have the collaboration between, as we call it, the Quadruple Helix: the sports association, knowledge institution, municipalities and business, those four parties that have to be busy with innovation".* The link with businesses is substantiated the interviewee's concern of developing an application together with a knowledge institution, that the private sector then is not interested in: *"Something is a super nice innovation and conceived from the knowledge institutions, for example in collaboration with the sports association. Only we miss the link to businesses [...] There is evidence it is a super cool innovation, but there is no match with businesses or they just don't know how to find the target group".*

Organisation C perceives there to be a pressure to uphold the reputation of the innovative status its country has: *"the country [anonymised] perhaps belongs to the most innovative associations internationally. […] That should be our goal, to belong there"*. Naturally, they also want to support their athletes to the best of their ability.

These case descriptions serve as a foundation for the analysis, facilitating the corroboration of findings and the identification of differences between the organisations. The cases have, so far, been described individually and independently. Chapter 5 provides a cross-case analysis based on the themes that are identified from the cases, unravelling the factors that facilitate and inhibit XR adoption.

4.4. Thematic Map

From the interviews, themes are generated as described in Section 3.4. These themes are displayed in the thematic map in Figure 8. The themes relate to each other, and some themes can be clustered together under a broader topic or overarching theme. The three major themes identified are: XR limitations, implementation method, and XR use cases. These will be explained in more detail below, including how the other themes relate to them. This discussion is relevant to illustrate how the identified facilitators and inhibitors have been determined.

4.4.1. XR limitations

XR limitations refer to the constraints that are inherent to extended reality which limit their ability to be applied in a sports context. One limitation for extended reality is the amount of time and money that has to be invested to create XR applications. This is in turn related to the difficulty in developing the software that is required for both the technical abilities of the applications as well as the contextual surroundings. Despite the steep costs for the development of the applications, they are still facing technical limitations. Some movements might not be displayed accurately, and actions that require a high degree of haptic feedback (throwing a ball) are currently not well-developed enough for elite athletes. Lastly, the lack of expertise that sport organisations have on the topic of extended reality can be considered a limiting factor. Extended reality requires knowledge on a hardware and software side, in addition to understanding how and where (not) to apply it. This makes it a complicated technology to implement. The next section looks at the implementation process further.

4.4.2. Implementation method

This theme relates to many organisational aspects and how they influence the way sport organisations implement extended reality. By being innovation-minded, which is caused by both self-imposed as external pressures, the organisations are pushed towards adopting new technologies in order to keep up with competition and technological developments. A strong network supports the implementation process. Especially in specific countries, organisations have an advantage here. Relatively small sized countries and high-quality infrastructure lead to technologies being more easily tested and distributed across many organisations. Organisations use either a bottom-up or a top-down approach for implementing extended reality. One is not necessarily better than the other, although a clear policy does appear to positively influence XR adoption. Having a clear policy on how and where to adopt XR can be considered an element of the top-down approach. The feedback that users provide to the organisation also influences how and where extended reality is implemented. This feedback is positive after trialling the technology, but is often first negative and a cause of resistance against the technology. This can be attributed to a lack of knowledge regarding XR; athletes and coaches have often never tried it before and are thus sceptical about its value. The lack of knowledge also causes resistance at the management level, together with concerns about the business case of the technology; how much has to be invested, and how much will that return (and at what risk). The implementation of XR is not impacted by regulations. Regulatory issues are only related to data storage and privacy concerns. The next section looks at how XR is used, after it has been adopted.

4.4.3. XR use cases

The last major theme is about the XR use cases, including ideas for future applications. These ideas have to be researched first to understand their effectiveness. The hardware that is available is developing quickly. Organisations can choose from a wide range of glasses, each with their own specialities and limitations. The hardware is rated positively, use cases of XR are only negatively impacted by the software side of the equation. There is already a varied range of XR applications that are currently used. An often utilised approach for these applications is that they were off-the-shelf products at first, which are adapted to the specific requirements of the organisation. There are many possibilities to utilise extended reality in a sports context, but the final three themes that are identified illustrate that the technology is mainly still used in an experimental phase. There are little to no augmented reality applications used, the applications that are implemented are used sporadically and in general XR for sports improvement is thought to be still in its infancy.

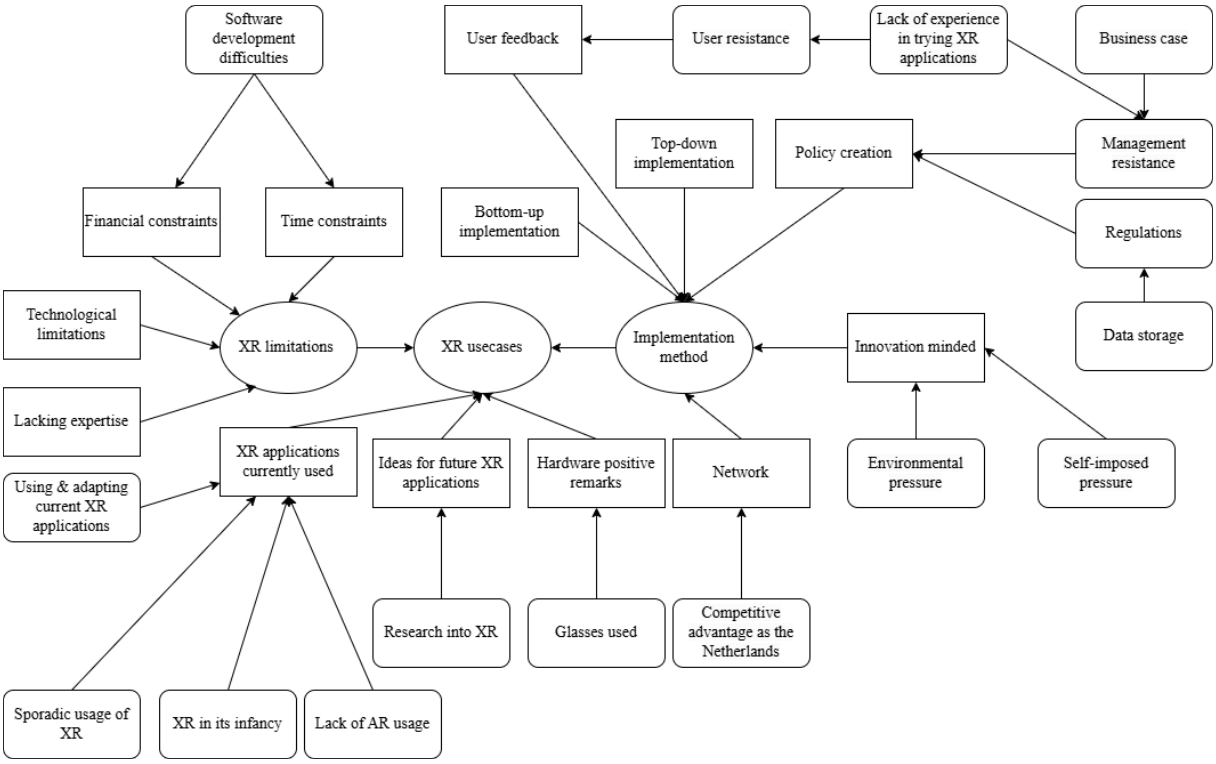

Figure 8. Thematic Map

The discussion above and Figure 8 illustrate the great degree of interconnectivity amongst all the themes. Some relationships are not even graphically depicted for the purpose of clarity; such as how research into XR can potentially reduce management resistance, or how a strong network can alleviate some of the difficulties with developing the required software.

The themes identified here are used to identify those topics or phenomena that either positively or negatively influence the adoption of XR. In some instances, multiple themes are clustered together for that. There are also themes that do not have such influence, and they are thus not relevant for the discussion of facilitators and inhibitors of XR adoption. This discussion is provided in Chapter 5.

4.5. Summary

This chapter describes each organisation in detail. The case description provide an analysis based on the three dimensions from the TOE-framework, and their corresponding factors (see Figure 7 in Chapter 3). Organisation A is a national governing organisation, both supporting the national federations and responsible for the athlete development towards the Olympics. Organisation A utilises

XR for various goals, and has included its adoption as one of their main strategic pillars for innovation. Organisation A collaborates with numerous external organisations, such as universities and private companies, to develop or enhance XR applications. Despite their clear policy, Organisation A is limited in its XR adoption by financial and time constraints. Organisation B, a commercial company that uses athlete sponsorships as part of their marketing strategy, does not have a clear policy on XR adoption. It is used sparingly for overcoming fears caused by e.g., accidents, or in injury rehabilitation programs. Organisation B is critical on the strategic value of XR, focusing more on human rather than technological intervention for athletes. Financial constraints play a role in the lacking XR adoption, but time constraints are more significant. Organisation B does not have a strong network of organisations they collaborate with for XR development, with the exception of one application developer they have a long-lasting project with. Lastly, Organisation C is a national federation, supported by Organisation A. Organisation C acknowledges the potential of XR for their athletes, and have piloted numerous projects. Time and, especially, budget constraints limit the further adoption of XR. The lack of policy and management support also hinder in its implementation. Organisation C collaborates extensively through a formalised network of knowledge institutions, (local) government, and private companies, for the development of, amongst others, XR applications.

The interviews and individual case descriptions are further used to develop the thematic map, depicted in Figure 8. This map illustrates how three major themes: XR limitations, implementation method, and XR use cases, are related and interconnected. Each of these themes stems from a variety of sub-themes. Figure 8 illustrates the complexity and the variety of factors involved in XR adoption. In Chapter 5, this is further elaborated upon by means of a cross-case analysis, and developed into facilitating and inhibiting factors for XR adoption.

5. Cross-Case Analysis

The thematic analysis of the interviews conducted with sports organisations results in a map, in which the themes and their relationships are displayed. This map, see Figure 8 in Chapter 4, is used to understand the ways in which specific topics and phenomena interact with each other. By combining the findings from the thematic map and a comparison of the interviewed organisations, the facilitating and inhibiting factors are identified.

5.1. The Organisations Compared

The three dimensions of the TOE-framework are operationalised through selected metrics, see Sections 3.2 and 3.3. The individual case descriptions in Chapter 4 have allowed for the evaluation of each interviewed organisation based on these metrics, which has generated both overlapping and differing findings. This section summarises the comparison of the interviewed organisations for each dimension of the TOE-framework.

The organisations differ in how they perceive the advantages of adopting XR and how much hindrance they encounter during this process, see Table 6. From the analysis of the technological context, it stands out that all interviewed organisations perceive moderate to high barriers for adoption. This means that the implementation of XR is significantly hindered, despite Organisation A and Organisation C rating its benefits highly. The high perceived benefits might be related to a lower degree of perceived barriers, this is substantiated in Table 7 and Table 8: increased time availability, clearer digital strategy, and a stronger network of partners can all be explanations for decreasing the barriers for XR adoption when comparing Organisation A and Organisation B to Organisation C. However, for an organisation to make more time available, develop a stronger digital strategy, or engage in partnerships, they must find it worthwhile. Given Organisation B's low rating of perceived benefits, they have not prioritised these elements (see Section 4.2).

The three organisations further differ in the purpose they use XR for, depicted by the categories utilised (see Table 6). These categories were identified and discussed in Chapter 2. All interviewed organisation indicated they are in the experimental phase regarding XR usage, but focusing on different application domains. The adoption of XR in such varied domains underlines versatility of XR for sports performance improvements. It also illustrates the different focal points of each organisation: whereas Organisation C focuses solely on mental performance and injury prevention, organisation A focuses on a specific event (e.g., the Olympics), and Organisation C adopts a wide range of applications, mainly based on the user performing sport-specific movements.

Table 6. Technological Context

	Organisation A	Organisation B	Organisation C
Perceived barriers	Moderate	High	Moderate
Perceived benefits	High	Low	High
Application usage			
Cognition	X	X	X
Motor skills			
Real-time feedback			X
Tactical analysis			
Pressure simulation	X		X
Sport-specific simulation	X		X
Injury prevention[14]		X	
Mental relaxation[15]	X	X	

[14] This category is utilised, but more in injury rehabilitation than in injury prevention.
[15] This category was not originally found through the literature review, but has emerged from the interviews.

The interviewed organisations all adopt an organic structure, see Table 7. This structure allows for greater flexibility (compared to a mechanistic structure), which helps to foster innovation (Burns & Stalker, 1961). Despite a structure that supports innovation, the resources available for innovation, specifically for XR innovation, differed. Organisation A and Organisation C are able to develop and adopt XR applications, but have to prioritise and select specific projects strictly to have enough time and budget. Organisation B has the financial means to pursue XR projects they are interested in, but do not have any time available to uncover which projects this should be. The XR applications that are currently utilised by organisation B have been adopted multiple years ago, further adoption had stagnated for over a year due to time constraints at the time of the interview. This might be explained by the lack of management support and policies regarding XR adoption. There are simply no employees designated to the task of researching the opportunities of XR, greatly limiting the time invested for this. Organisation C faces similar struggles, as limited support and unclear policies have resulted in insufficient time and a lack of clear direction for XR adoption projects. Organisation A has formalised the importance of XR into a digital strategy for the upcoming Olympic cycle (until 2028). When projects are piloted, the management of Organisation A is more supportive than in Organisation B and Organisation C, given that these projects are part of their digital strategy. Because of this, Organisation A can dedicate more (although still limited) time to researching XR. This is reflected in the roles of those responsible for XR adoption. In Organisation A, a three-person department dedicated to technological innovation includes one individual formally responsible for XR adoption, among other domains. In Organisation B, no one is specifically assigned to XR; employees independently experiment with applications on an ad hoc basis. In Organisation C, the head of sport science explores XR possibilities but must balance this responsibility with numerous other tasks.

Table 7. Organisational Context

	Organisation A	Organisation B	Organisation C
Structure	Organic	Organic	Organic
Complexity	*Low*	*Low*	*Low*
Formalisation	*Low*	*Moderate*	*Low*
Centralisation	*Moderate*	*Moderate*	*Moderate*
Resource availability	Limited	Limited	Limited
Financial availability	*Limited*	*Sufficient*	*Limited*
Time availability	*Limited*	*Insufficient*	*Limited*
Top management support	Extensive	No	Limited
Innovation policies	Clear	Not existing	Limited

The third dimension, the organisation's environment, clearly illustrates two distinct fronts: Organisation A and Organisation C, who have an extensive network of partners, and Organisation B, which operates largely alone for XR adoption (see Table 8). In the case of Organisation C, their network is even formalised through [anonymised]. Organisation B only has a single partner for XR, in the form of a development project with a major application developer. This might be explained by the lack of perceived competitiveness, reducing the pressure on engaging in partnerships to maintain or gain a competitive advantage. The aforementioned factors of a lacking digital strategy and lower perceived benefits of XR adoption also can play a role in a reduced need for developing and maintaining an infrastructure that supports XR adoption. All interviewed organisations are free of regulatory constraints regarding XR adoption, besides complying with laws and internal policies related to privacy and data storage.

Table 8. Environmental Context

	Organisation A	Organisation B	Organisation C
Supporting infrastructure	High	Low	High
Number of partners	*High*	*Low*	*High*
Closeness of partners	*High*	*Moderate*	*High*
Industry competitiveness	Moderate	Low	High
Regulations	Limited	Limited	Limited
Government regulations	*Limited*	*Limited*	*Limited*
Internal policies	*Limited*	*Limited*	*Limited*

Although it appears that Organisation A and Organisation C are very similar, they differ on key points. The formalised manner in which Organisation A has included XR adoption into their digital strategy allows for a smoother and more (management) supported adoption process. Additionally, despite both being evaluated as 'limited' on resource availability, this issue is more stringent for Organisation C than for Organisation A. Organisation B has more obvious differences regarding XR adoption, to which the perceived value of XR lays at the foundation. The discussion of similarities and differences continues in the next section, where they are used to identify facilitating and inhibiting factors for XR adoption.

5.2. Facilitators and Inhibitors

The comparison of the interviewed organisations illustrates that they are all currently experimenting with XR applications, albeit for different purposes and with different degrees of importance. The organisations also share a common goal, which is to support their athletes to the best of their abilities. Below, each construct that contributes to or hinders XR adoption is discussed, which culminates in Figure 9 where these findings are summarised. The factors are identified by the findings of the thematic map (see Figure 8 in Chapter 4) in conjunction with the comparison of the evaluated metrics in the section above. Some factors currently promote, and others discourage the adoption of XR in the interviewed organisations. How each factor influences XR adoption in the three organisations is depicted in Table 9.

Digital strategy clarity

Organisation A is the organisation which has the clearest digital strategy on XR adoption, and utilises a top-down approach in the implementation of the technology. The Organisation B adopts a bottom-up approach, where specialists in a specific field (e.g., for mental performance) discover and experiment with certain XR applications themselves. They maintain a 'human before technology' approach. Organisation C sits somewhere in the middle, without a clear policy on extended reality implementation but with a specific person/department who is responsible for its usage. The people with the specific role of investigating XR and pushing for their usage can be considered as innovation champions, which Baker (2012) identified as an important factor for the organisational context to adopt new technology. The same hierarchy, from a clear digital strategy to no strategy, is reflected in how much the organisations experiment and use extended reality; Organisation A and Organisation C use and experiment with XR in different settings and for different purposes, while Organisation B focuses specifically on mental performance and rehabilitation and uses it much less.

Innovation pressure

Organisation A and Organisation C perceive external pressure to innovate and utilise new technologies. Organisation B perceives pressure to a lesser degree, by the lack of direct competition they have. The pressure causes the organisations to have an outward look for new technologies, such as extended reality. The innovative status of the country they are situated in contributes to the pressure perceived by the Organisation A, but especially the Organisation C. They want to be on the forefront of technological developments and are thus experimenting with extended reality in various ways. In the interviewed organisations, a greater degree of perceived pressure for innovation correlated to greater degrees of XR adoption. The position a sports organisation holds relative to their competitors, and the (innovative) effort required to maintain this position, relates to how much organisations will focus on adopting XR applications: Organisation B evaluates themselves as having a unique position in the industry, without significant direct competition, and also have focused the least on XR when compared to Organisation A and Organisation C.

Network strength

The collaboration with multiple parties, such knowledge institutions, businesses, (local) government, and other sport organisations is a large contributor to the XR experimentation and adoption for Organisation A and Organisation C. The government can provide subsidies for innovation, knowledge institutions conduct specific research into XR applications, and businesses develop new applications and ensure economic vitality of applications. In Organisation C's country, this network is formalised through [anonymised]. If an organisation is situated in a country where there are less external partners related to XR available, this can hinder the development of applications and consequent adoption processes.

Once an application is found that suits the needs of the sport organisations, the ability to collaborate with the supplier rather than just consume the product is another important network element. All interviewed organisations have used existing applications and customised them with the application developer specifically to their demands. Organisation A and Organisation C did this on a smaller scale, while Organisation B has had a long-lasting project with a prominent application developer to develop their own XR applications.

Budget

Naturally, the amount of time and money available to research, develop, and implement extended reality is an important factor. The interviewed organisations are limited in this regard. At Organisation A and Organisation C there is one person who is responsible for testing and implementing extended reality, and this is just a component of their job. Organisation B did not have any time to research how they could utilise extended reality until they assigned this task to an intern. Besides time, financial constraints are also present. The development extended reality applications is expensive, and budgets for such new and not yet established technologies limited. In addition to application development, hardware has to be purchased as well. This makes extended reality a technology with relatively high entry barriers from a financial standpoint, and is attributed as part of the reason that the organisations are still in experimental phase regarding its implementation. If an organisation rates the benefits of XR highly and has the financial means, this factor can relatively easily positively influence XR adoption. By having a higher budget available, more applications can be developed, tested, and adopted.

Management support

Management support was already discussed in Chapter 3 to be important for digital transformation initiatives (Baker, 2012; Chanias & Hess, 2016). The lack thereof varies in each of the organisations, but they all face resistance from management in some way. It is attributed to lacking knowledge and scepticism on the topic of XR, which can be hard to overcome when managers do not take sufficient time to try out the technology themselves. Additionally, the resistance from the management can come from a lack of confidence in the technology, or having to make the trade-off between investing in XR, another technology, or e.g. a new coach. The business case of investing in extended reality is not always clear, which leads to scepticism from the higher organisational layers.

Management support, or resistance, relates to other facilitating and inhibiting factors as well. A lack of support results in less clear policies for extended reality usage, as in the case of Organisation C, or a clear policy but with a lower priority for XR, as is true for Organisation A and their pillars for innovation. Management also plays a role in budget allocation, both in time and financial dedication. A supportive management can allocate adequate resources for XR adoption, whereas a sceptical management towards XR adoption might prefer to focus on other projects.

User support

Encouragement or resistance to new technologies can promote or hinder the adoption of XR within sports organisations. While athletes at Organisation B are reportedly enthusiastic about incorporating XR into their training programs, Organisation A and Organisation C face more difficulties in this domain. Both athletes and coaches in these organisations express initial scepticism, often prioritising traditional training methods over testing and adopting new technologies. This resistance stems from a preference for focusing on established routines rather than investing time in unfamiliar tools that may not deliver immediate results. However, once users have the opportunity to experience XR, their perceptions tend to shift. Coaches and athletes who initially resisted the technology often recognise its value and become more open to integrating it into their practices. This pattern suggests that the primary barrier lies in overcoming the reluctance to try XR for the first time. By educating the users and illustrating the way in which XR is supposed to help them, this reluctance can be decreased. In Organisation A, the positive feedback from the athletes after a pilot at the Olympics was used to promote the development and adoption of other XR applications, illustrating how user support can also boost XR adoption.

Furthermore, sports organisations should consider in which processes to implement XR first. Athletes and coaches are likely to exhibit more resistance when XR is adopted in key trainings. However, if the athletes can experiment with XR for less important processes, e.g., pre-training visualisation exercises, they can be more easily inclined to test the technology, as this is less invasive to their most vital activities. Their initial resistance might turn into a supportive mindset towards XR applications, if the pilots were perceived as useful and effective for performance improvements.

XR applications maturity

This factor currently inhibits XR adoption, and refers to both the applications themselves being in their infancy as well as the usability of the applications being in their infancy. Despite generally positive findings regarding XR usage to improve performance in sports, many important questions still exist, especially at the elite level of sports. Skill transferability, realistic movement patterns and physics, and longitudinal effects of training with XR are all concerns to which research findings are limited. This results in caution from the sport organisations in whether, how, and where to implement extended reality. Of course, scepticism towards new technologies is healthy, and organisations are not expected to implement everything without clear indications of its usefulness. However, combined with budget constraints and management resistance, this factor can hinder adoption substantially. This prevents management and user resistance to be overcome by illustrating the positive effects of XR for performance improvements, leaving the technology in a difficult spot. If the maturity of XR for sport performance increases, in the form of e.g., better applications, research on its effectiveness, and successful pilot projects, it is likely that this will attract sports organisations to adopt XR further. This is illustrated by the current projects the interviewed sports organisations have adopted: those all rely on VR. AR and MR applications for sports performance are said to be not mature enough yet, although promising for the future (see Section 4.3). Increased maturity in VR has led the interviewed organisations to pilot projects with this technology, a similar pattern can be expected when AR and MR applications develop further.

Software development capabilities

The development of the XR applications is currently deemed a large difficulty for the interviewed organisations. In order for the application to work well for elite athletes, they have to be accurate in how they represent movement. Besides their functionality (e.g., playing tennis, practicing archery), the context should be adaptable for most purposes as well. The archery practice application from Organisation A had to be custom-made to look like the Paris 2024 Olympics stadium. The programming in order for the applications to be suited for sport organisations requires many hours, and is costly. This relates to the budget constraints the interviewed organisations faced. The interviewed sport organisations do not have such programmers in-house, requiring them to outsource these tasks to external parties. A strong network and collaboration with application developers can in turn facilitate the adoption of XR applications. Alternatively, sports organisations can increase their software development capabilities to be able to create XR applications (partly) in-house. This would alleviate the current strain on XR adoption caused by software development difficulties, instead turning into an organisational strength.

Table 9. Facilitators & Inhibitors for the Interviewed Organisations

	Organisation A	Organisation B	Organisation C
Digital strategy clarity	Facilitator	Inhibitor	Inhibitor
Innovation pressure	Facilitator	Inhibitor	Facilitator
Network strength	Facilitator	Inhibitor	Facilitator
Budget	Inhibitor	Inhibitor	Inhibitor
Management support	Facilitator	Inhibitor	Facilitator
User support	Inhibitor	Facilitator	Inhibitor
XR applications maturity	Inhibitor	Inhibitor	Inhibitor
Software development capabilities	Inhibitor	Inhibitor	Inhibitor

The identified factors are consistent with existing literature, as Alam et al. (2021) identify similar factors in a study on AR adoption in the retail industry. Table 9 shows the differences between the organisations for the identified factors. Whether a factor facilitates or inhibits XR adoption is based on the individual case description in Chapter 4, of which the main points are summarised in Table 6, Table 7, and Table 8. These differences can be mainly attributed to the strategic priority assigned to XR and the organisational readiness for its adoption. The current immaturity of the existing XR applications is an external factor, impacting all three organisations. In the case of Organisation A, budget and further maturity within the XR applications are the main constraining factors. Organisation B prioritises XR too little, limiting the organisation in many aspects for extensive adoption projects. Organisation C is situated in the middle of Organisation A and Organisation B: the organisation is interested in XR but appears to not be ready for a dedicated program of XR adoption.

5.3. TOE-Framework for XR Adoption

The abovementioned facilitators and inhibitors are graphically depicted in Figure 9. The three dimensions of the TOE-Framework are analysed based on the selected metrics. The dimensions are shown as input for the identified factors, by means of a dotted line. The facilitating and inhibiting factors in turn influence XR adoption. Each factor can either positively or negatively affect the degree to which XR is adopted. An organisation might, for example, have a management that greatly supports innovative initiatives, and strongly encourages the development of XR applications. In this case, manage support acts as a facilitator. If the management of an organisation is indifferent to XR technology, it will likely not be a strategic priority. The allocated resources and effort dedicated to developing a network of partners might then be insufficient for high degrees of XR adoption.

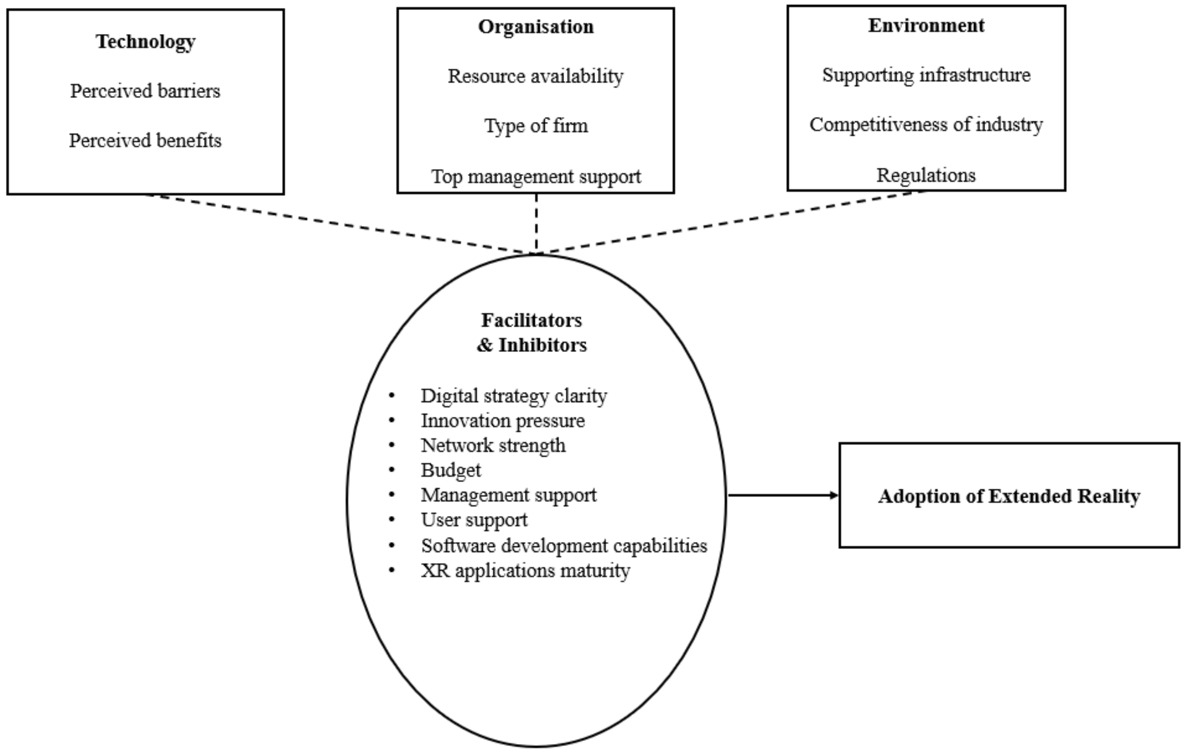

Figure 9. TOE-Framework Adapted for XR Adoption in High Performance Sports Organisations

The TOE-framework in Figure 9 is adapted to be used specifically for XR adoption in high performance sports organisations. Organisations can use the metrics that make up each of the three dimensions of the TOE-framework to evaluate themselves, similarly as done in Section 5.1. By utilising the identified factors from Figure 9 and an organisation's evaluation, the organisation can discover what is positively and negatively influencing their XR adoption, as done in Table 9. This can inform the decision-making process regarding improving XR adoption.

5.4. Summary

This chapter discusses the three interviewed organisations in a comparative way, based on the metrics determined in Chapter 3. Each organisation has unique attributes. Organisation A and Organisation C rate the benefits of XR highly, while Organisation B is more sceptical (see Table 6). The purpose for which XR is adopted also differs per organisation, see Table 6. The interviewed organisations are structured similarly, and can be categorised as organic (see Table 7). The degree to which XR adoption is included in internal policies and supported by management varies greatly between the interviewed organisations: Organisation A most strongly internalised XR adoption in their processes, followed by Organisation C, and lastly Organisation B. Whereas Organisation A and Organisation C have a strong network of partners, Organisation B operates largely independently (see Table 8). This same distribution is true for the perceived external pressure for adoption: Organisation B barely perceives any external pressure in this regard, while Organisation A and Organisation B use this as a motivation to adopt XR.

The differences between the interviewed organisations and the thematic map in Chapter 4 have led to the identification of the facilitating and inhibiting factors: digital strategy clarity, innovation pressure, network strength, budget, management support, user support, software development capabilities, and XR applications maturity. How each factor impacts the XR adoption of the interviewed organisations is depicted in Table 9. The identified factors are used to develop an extension of the TOE-Framework, by specifically adapting it to the research context, see Figure 9. Depending on the organisation's strategic priority and organisational readiness regarding XR adoption, the factors can both positively and negatively affect the degree to which XR is implemented. The implications of the identified facilitating and inhibiting factors for the academic world, as well as for managers of sports organisations is further discussed in Chapter 6.

6. Discussion & Conclusion

Using a multiple-case study approach and the TOE-framework, this study identifies key facilitators and inhibitors, providing insights for organisations to implement XR and improve their athletes' performance. These factors, see Chapter 5, provide insight into the elements that influence XR adoption. Building on those influencing factors, this chapter discusses the current state of the sports industry regarding XR adoption. Furthermore, conclusions to the research are presented, revealing an industry in its experimental phase, where potential is high but realisation of this potential is constrained by internal and technological limitations. The chapter finishes with the study's implications, limitations, and recommended future research directions.

6.1. State of the Industry

In addition to identifying the facilitating and inhibiting factors, the secondary goal of this research is to identify the current state of the industry with regard to XR adoption and usage. The interviewed organisations are interested in the opportunities that lay within extended reality, but keep a certain scepticism towards how and where to adopt it. Current extended reality usage is limited, but growing. This can be mainly explained by the organisational capabilities, who might not have enough experience, time, or funds to properly experiment with extended reality. Another major influence on the limited XR usage lay within the technological capabilities. Many applications for sports exist, but not all are relevant for high-performing athletes. On both the supply and demand sides of the equation, the XR for sports performance industry remains in its infancy. Sports organisations are yet to commit themselves strongly to XR adoption, and XR applications should continue to be developed for increased useability.

This results in the experimental phase in which the sports industry appears to be, with regards to XR usage. Organisations differ in the degree to which they experiment, as Organisation A and Organisation C have more projects than Organisation B (see Table 6 in Chapter 5). However, for all of the interviewed organisations it remains true that extended reality is used exploratively and in pilots. XR applications have been adopted for all categories except for 'motor skills' and 'tactical analysis' by the interviewed organisations. This means that, despite the lack of maturity in XR usage, organisations are experimenting with it on a broad scale. Some future applications into these missing categories were mentioned, such as a scenario decision-making tool (see Section 4.1). However, technological constraints currently hinder its development.

Sport organisations are trying out and thinking about new processes where they can adopt extended reality. The degree to which they succeed in this is strongly related to the facilitators and inhibitors of adoption, see Chapter 5. From these findings, it appears that Organisation A is the most mature regarding XR adoption. Organisation A has leveraged the most factors as facilitating the adoption process compared to Organisation B and Organisation C (see Table 9 in Chapter 5). Organisation C follows in the ranking of maturity, despite several inhibiting factors. Organisation B appears to not be ready to adopt XR at a large scale, however, from the interview it also became clear that this is not a top strategic priority for the organisation (see Chapter 5).

6.2. Conclusion

This research has identified eight factors that influence XR adoption: digital strategy clarity, innovation pressure, network strength, budget, management support, user support, software development capabilities, and XR applications maturity. The identified factors and how they facilitate or inhibit XR adoption illustrate a paradox in the adoption of extended reality by sports organisations: while XR has the potential to significantly contribute to improved sports performance, its adoption is hindered by a lack of strategic priority and organisational readiness. The interviewed organisations are currently lacking a clear digital strategy for XR, attributed by the interviewees to the low strategic priority management has given this technology. Only Organisation A has included XR in their digital strategy, but the interviewee indicated that it is the least prioritised technology. The absence of a high priority causes a plethora of issues that inhibit the adoption of XR. The interviewed organisations all state to be limited in their resources available for XR development, and any development that occurs faces minor to significant resistance from both users and management. This is correlated with the unreadiness of the interviewed organisations to adopt XR. Although Organisation A and Organisation C have developed extensive networks, they are insufficiently capable of widespread adoption of XR. In Organisation B, this phenomenon is present more strongly, as even the supporting network is missing. These processes reinforce themselves. For instance, network strength can facilitate innovation by enabling collaboration with developers, thus addressing software development difficulties and lowering cost barriers. Conversely, management resistance results in unclear strategy and insufficient budget allocation, which makes it more difficult for pilot projects that could reduce scepticism from management to be undertaken, creating a vicious cycle that hinders XR adoption. This interconnectedness illustrates that XR adoption is not solely a technical issue, but one that encompasses the entire organisation, requiring alignment across management, policy, and networks.

Although the initial analysis presents several challenges, the prospects for the future remain promising. All three interviewed organisations are currently developing internally to improve their ability to adopt XR. Organisation A is increasingly piloting projects, with success. Organisation B has generated an extensive overview of current applications they deem useful, and is spending more time on researching the effectiveness of XR for their athletes. Lastly, Organisation C has the goal of restructuring their departments to create jobs that specialise in technological innovation, among which XR. This should enhance their capability to try out new and different XR applications. For all three organisations, the user and management support should increase as the number of XR applications adopted grows, as the current finding is that after trying out XR initial scepticism is turned into enthusiasm.

Besides these two internal factors (strategic priority and organisational readiness), technological maturity also hinders the current adoption of XR. This is substantiated by statements of all three organisations regarding the efficacy of using XR to enhance sports performance, as well as the literature study conducted in Chapter 2. Specific applications, long-term usage effects, and skill transferability are some of the key areas that are currently under-researched. The applications that currently exist are showing signs of improving athletic performance, but there are few studies done focusing on the elite level in sports. XR still has a way to go in terms of development for its usage to be widespread among sports organisations, since the current applications are often too limited in how they can be deployed. Further growth in the degree of realism, possibilities within applications, and research on skill transferability and long-term effects will likely contribute to XR adoption, independently from the organisational internal developments. Fully customised applications currently appear to be the most promising, as Organisation A and Organisation C pilot such applications the most. However, as stated by all three interviewed organisations, such applications are requiring significant investments, which is not feasible given the constrained resources. For Organisation B this is the reason to focus mainly on readily available applications, which in turn are less effective in performance improvements at the highest level in sports.

This appears to be a vicious cycle for current XR adoption practices in sports organisations: the organisations themselves are not prioritising or not able to adopt XR at a systematically, partly because of internal reasons and partly because the technology is not developed sufficiently yet. This lack of development is provided by the participating organisations as a reason for a rather hesitant approach to XR adoption, and deters them from putting the technology higher in priority. Furthermore, the lack of XR adoption hinders the development of the technology for sports performance purposes, as projects created specifically for this purpose are only conducted scarcely.

To cope with this reinforcing cycle, it is recommended for sports organisations to develop internally such that XR can be adopted efficiently. This can be done through an analysis of the inhibiting and facilitating factors. Pilot projects should be conducted, but organisations are recommended to take a reserved stance regarding systematic and large scale XR adoption. Sports organisations should keep XR on their radar, as it is a dynamic technology that has developed rapidly over the past few years. However, XR is currently not mature enough to justify significant investments. More developments should be done on XR applications themselves and the research testing its efficacy for performance improvement before sports organisations convert to internalising XR completely into their training and/or race preparation processes. It is important for sport organisations to already form a clear vision and improve internal alignment for XR adoption, despite the flaws and limitations the technology has. Closely following the technological developments in XR and increasing the organisational readiness, allows organisations to more effectively adopt XR once it reaches a sufficient level for widespread implementation. By being early adopters, the sport organisations can gain a competitive advantage in the future. This is illustrated by other innovation adoption within the sports industry as well, such as precise nutrition tracking in cycling[16] and the usage of data analytics in American Football[17]. If managed well, XR has the potential to transform training, competition, and recovery, leading to a new important type of innovation for high-performance sports.

This study adds to the current literature by extending the TOE-framework and adapting it to the specific context of XR adoption in sports, enhancing the understanding of the factors influencing XR adoption. Although the TOE-framework has been used in other technology adoption studies, this study applies it in a novel context. The study demonstrates the reinforcing nature of facilitating and inhibiting factors, contributing to the understanding of the XR adoption process as a holistic phenomenon. Furthermore, it has been demonstrated that the factors influencing the adoption of XR are not only shaped by the technology itself, but also by the organisation's maturity and environmental pressures. This work also contributes to the broader field of sports innovation systems, specifically in understanding how sports organisations adopt high-tech applications. These findings offer a theoretical foundation for exploring other technological innovations within this domain. Furthermore, the practical findings from organisations underline the importance of more studies researching XR for sports performance. The identification of the industry demand for more clarity on the efficacy of XR for improving athletic performance can aid in the strengthening of this research field, by increasing the number of studies on the topic. The research contributed to a research gap on practical insights of XR usage in the sports industry, on which currently no other studies exist.

The results also have practical implications. The study provides practitioners with an overview of where extended reality applications can be used for. Furthermore, a better understanding of the facilitators and inhibitors specifically to the sports industry for XR adoption can help decision makers in developing a strategy that builds on the facilitating factors and reduces the inhibiting factors. This will enable a more effective approach to adopting extended reality. By, for example, providing pilots of extended reality applications to management, their resistance to investing in the technology might be reduced. Developing strong connections with knowledge institutions allows the sport organisations to empirically test whether applications are improving performance, which can further increase trust in extended reality. Furthermore, a general vision on the recommended organisational stance towards XR is provided. This helps management categorise the technology of XR within their innovation portfolio. The current state of XR is too immature for large-scale adoption, and its development is dynamic. Practitioners should thus keep XR on their radar to stay informed about relevant refinements in the technology, while simultaneously preparing their organisation for future adoption projects. This can go hand in hand with running pilot projects, familiarising the users and management with XR and its adoption process.

[16] https://www.theathletesfoodcoach.com/
[17] https://operations.nfl.com/gameday/analytics/big-data-bowl/

6.3. Limitations & Future Research Directions

The study is not without limitations. Firstly, as the insights are limited to describing and explaining the views of the participants, it is not possible to elaborate further on the findings. It is unclear which of the factors most effectively enhance the adoption of XR in sport organisations, similarly the findings to do not explain which factors restrict XR adoption most. This descriptive approach does not prioritise the identified factors, leaving room for further exploration with more quantitative or comparative methods. Additionally, the use of thematic analysis to identify these factors introduces the potential for researcher bias, as the interpretation of themes is subjective. While steps were taken to ensure rigor, this methodology may affect reproducibility of the findings. Confidentiality concerns further impacted the study's transparency. Although the organisations were described, it is not possible to fully contextualise the findings without disclosing the names of the participating organisations.

Secondly, the study consisted of only three organisations. The wide selection of organisational types resulted in insights from different perspectives, but can also lead to a lack depth. The three organisations are all prominent actors in the sports industry, smaller organisations might face distinct influencing factors. The organisation all deal with international components, but two of the organisations are based in the same country. These concerns can all limit the degree to which findings can be generalised to other organisations. Furthermore, the study relied on interviews with only one participant per organisation, holding a specific role related to (using) XR. This approach was necessitated by time constraints within the participating organisations. This might cause an incomplete image of XR adoption, as not all perspectives within each interviewed organisation are included. Self-reported data by the interviewees also introduces bias, as interviewees may lack full knowledge of XR adoption across their organisations or may portray the organisation in a more favourable light. A wider range of organisations or more in-depth analysis of a single organisation, with e.g., a longitudinal scope or from various perspectives, can overcome these limitations and strengthen the findings from this research.

Thirdly, the TOE-framework utilised in this study provided an organisational perspective to XR adoption, but largely overlooks the individual level (a manager, athlete, or coach, for example). The study identified numerous factors related to this level, underlining the importance of the individual for XR adoption. These factors could not be analysed in great depth with the current methodology. For this purpose, a framework such as TAM is more suitable.

Furthermore, there were areas of XR adoption where misalignment between the literature and practice emerged. For instance, while XR for injury prevention is frequently discussed in the literature, the organisations in this study utilised XR more for injury rehabilitation, an application not widely covered in the reviewed studies. The topic of (mental) relaxation after competition did not emerge from the literature at all, despite this being an important use case of XR for Organisation A and a piloted project at Organisation B. These gaps highlight the evolving and dynamic nature of XR applications used in sports and the importance of continued research to keep up with the developments.

Lastly, as XR is evolving rapidly, the relevance of the study findings might be limited over time. The findings are based on the current state of XR adoption practices and usage within the selected sports organisations, who all stated to be developing more focused approaches to adopt XR. This means that the facilitators and inhibitors identified in this study might shift in importance over time, or even become irrelevant (and new facilitators and inhibitors might be introduced). This, again, highlights the importance of future research to keep investigating XR in the sports industry as the technology and the organisations themselves keep evolving.

Besides the suggestions for overcoming the limitations of this research as future research directions, there are several more promising topics to be studied. This study has illustrated how organisations are currently adopting and using the technology, which has provided insights into the current gap between application development, XR for sport research, and practice. Future studies should be conducted on the numerous topics that arise from this gap. Current literature focuses strongly on technological development and capabilities. This is still important, as XR has not reached maturity yet. However, this research has underlined the importance of the organisational aspect to XR adoption, which is currently not reflected XR research, as the literature review in Chapter 2 illustrates. Future research can consider the long-term impacts of extended reality usage, once the technology is more grounded in the organisations' processes. Another venue for research can be on the topic of leveraging other technologies combined with extended reality, e.g., the usage of big data and AI to further improve existing applications. The aim of XR adoption in this study is to improve athlete performance, but extended reality can also provide numerous opportunities for commercial or marketing purposes. How organisations adopt the technology for this purpose is a relevant topic, since this might provide a financial incentive to further develop XR applications. The current study approach did not allow for a prioritisation of the different factors. Future studies can consider investigating causal relationships between the facilitators and inhibitors and XR adoption, to determine which of the factors have the most significant impact. Furthermore, it might be insightful to research specific facilitators or inhibitors identified by this study. By e.g., considering change management frameworks and looking at management resistance, findings on a more detailed level might be discovered. Lastly, considering XR as a technology that is part of an organisation's portfolio of R&D projects can help those organisations in the categorisation and prioritisation of XR adoption. This provides organisations with strategic level recommendations on XR adoption. This can be done through researching XR for sports performance through the lens of e.g., MacMillan and MacGrath's (2002) R&D Project Portfolio Framework, which labels projects based on technology and market uncertainty. This research provides the basis for future studies on this topic, explaining both uncertainty dimensions. However, a more focused approach will likely lead to more detailed insights.

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Appendix

Appendix A: supporting tables

Table 10. Literature Overview

Name	Type of Research	Short Explanation
Bourhim, E. M., & Labti, O. (2023b). Reshaping Sport with Extended Reality in an Era of Metaverse: Insights from XR the Moroccan Association Experts. In *Studies in computational intelligence* (pp. 165–185). https://doi.org/10.1007/978-3-031-48397-4_9	Review.	SWOT and AHP analysis is conducted on the topic of XR technology for sport, providing insights for all stakeholders.
Geisen, M., & Klatt, S. (2021). Real-time feedback using extended reality: A current overview and further integration into sports. *International Journal Of Sports Science & Coaching*, *17*(5), 1178–1194. https://doi.org/10.1177/17479541211051006	Review.	Discussion of using XR to provide real-time feedback in different sectors is provided, which is in turn translated to usability for (performance) sport. Future development directions for XR in sport are suggested.
Geisen, M., Mat Sanusi, K. A., Baumgartner, T., & Klatt, S. (2022). XR Golf Putt Trainer: User Opinions on an Innovative Real-time Feedback Tool. *Proceedings Of The Second International Workshop On Multimodal Immersive Learning Systems*. https://ceur-ws.org/Vol-3247/paper7.pdf	Specific application testing.	XR system to practice putting in golf is developed. Users found it a useful tool, no measurements for improvements are given.
Geisen, M., Nicklas, A., Baumgartner, T., & Klatt, S. (2023). Extended Reality as a training approach for visual real-time feedback in golf. *IEEE Transactions On Learning Technologies*, 1–11. https://doi.org/10.1109/tlt.2023.3322660	Specific application testing.	XR is tested as a technology to improve putting in golf, illustrating the technology's capacity for enhancing motor skills through real-time feedback. Putting improvement was similar as with a physical instructor.
He, W., Chen, Y., Xu, S., Ding, C., Lee, L., & Lin, G. 2023. Dragon Boat Simulation: An Immersive Experience Beyond Traditional Gaming. *The 2023 ACM Symposium on Spatial User Interaction (SUI '23)*, https://doi.org/10.1145/3607822.3618022	Specific application testing.	An immersive rowing simulator is developed, allowing to row on the Guangdong river. The simulator included realistic resistance on the peddling system.
Heo, M.-H., & Kim, D. (2021). Effect of Augmented Reality Affordance on Motor Performance: In the Sport Climbing. *Human-centric Computing And Information Sciences*, *11*, 40. https://doi.org/10.22967/HCIS.2021.11.040	Specific application testing.	A system is developed that augments a virtual character on a climbing wall, to show how to do a climbing route. This improved participants' motor performance

		similarly to when a real instructor illustrated the route.
Kim, A., & Kim, S. (2024). Engaging in sports via the metaverse? An examination through analysis of metaverse research trends in sports. *Data Science And Management*. https://doi.org/10.1016/j.dsm.2024.01.002	Review.	Semantic analysis and topic modelling analysis is conducted on sport metaverse research. They find that games and videos are highlighted as important themes. Performance is prominently present as word in the literature.
Kim, J., Ka, J., Lee, Y., Lee, Y., Park, S., & Kim, W. (2022). Mixed Reality-based Outdoor Training System to Improve Football Player Performance. *2022 International Conference On Engineering And Emerging Technologies (ICEET)*. https://doi.org/10.1109/iceet56468.2022.10007354	Specific application testing.	A mixed reality outdoor football simulation is developed, that can be used by players and coaches to analyse tactical situations from past games or imaginary scenarios.
Lee, J., Yoon, H., & Kim, D. (2023). Design of Metaverse-Based Physical Fitness Service for the Enhancement of Exercise Capability for Youth. *Journal Of Mobile Information Systems*, *2023*, 1–19. https://doi.org/10.1155/2023/7272781	General application development.	A metaverse application for exercise guidance in youth is developed. The system uses an AR-based smart mirror. It collects movement data and provides posture accuracy feedback, so no coach is needed.
Noury, P. J. L., Polman, R. C., Maloney, M. A., & Gorman, A. D. (2023). XR Programmers Give Their Perspective on How XR Technology can be Effectively Utilised in High-Performance Sport. *Sports Medicine - Open/Sports Medicine - Open*, *9*(1). https://doi.org/10.1186/s40798-023-00593-5	Review.	Strengths and weaknesses for XR in sport are discussed, with possible directions for the future as well.
Noury, P. L., Buszard, T., Reid, M., & Farrow, D. (2020). Examining the representativeness of a virtual reality environment for simulation of tennis performance. *Journal Of Sports Sciences*, *39*(4), 412–420. https://doi.org/10.1080/02640414.2020.1823618	Specific application testing.	A VR tennis simulator is developed, to train perceptive-cognitive skill. The system is tested, and found to be sufficiently representative of the real world.
Noury, P. L., Polman, R., Maloney, M., & Gorman, A. (2022). A Narrative Review of the Current State of Extended Reality Technology and How it can be Utilised in Sport. *Sports Medicine*, *52*(7), 1473–1489. https://doi.org/10.1007/s40279-022-01669-0	Review.	A general review for usability, representativeness, and future development of extended reality technologies for elite sports is provided. History of development and main definitions of important concepts are discussed.

Ono, T., & Ishikawa, T. (2023) A Research on Penalty Kick Training System Using XR, *2023 Nicograph International (NicoInt)*, 86-86, https://doi.org/10.1109/NICOINT59725.2023.00026.	Specific application testing.	The trajectory of a ball in penalty shooting can be simulated in a digital environment using XR.
Orlandi, L., Martinelli, G., Laiti, F., Lobba, D., Bisagno, N., & Conci, N. (2023). Meta-Trainer: An Augmented Reality Trainer for Home Fitness with Real-Time Feedback. *International Workshop On Sport, Technology And Research (STAR)*. https://doi.org/10.1109/star58331.2023.10302670	Specific application testing.	A trainer avatar in an AR-environment is developed. The avatar shows an exercise, which the participant can see from all angles. When doing the exercise themselves, real-time feedback is provided.
Reneker, J. C., Pannell, W. C., Babl, R. M., Zhang, Y., Lirette, S. T., Adah, F., & Reneker, M. R. (2020). Virtual immersive sensorimotor training (VIST) in collegiate soccer athletes: A quasi-experimental study. *Heliyon*, *6*(7), e04527. https://doi.org/10.1016/j.heliyon.2020.e04527	Specific application testing.	Nine VR exercises to improve sensorimotor control are tested for football athletes, to see how they improve performance. There is a significant increase in 7/9 exercises, however, no changes in injury rate or on-field performance with control group.
Richlan, F., Weiß, M., Kastner, P., & Braid, J. (2023). Virtual training, real effects: a narrative review on sports performance enhancement through interventions in virtual reality. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1240790	Review.	Review of intervention studies using VR to improve performance in sports. Often there is a significant improvement, even outperforming traditional training mechanisms.
Schuermans, J., Van Hootegem, A., Van Den Bossche, M., Van Gendt, M., Witvrouw, E., & Wezenbeek, E. (2022). Extended reality in musculoskeletal rehabilitation and injury prevention - A systematic review. *Physical Therapy in Sport*, *55*, 229–240. https://doi.org/10.1016/j.ptsp.2022.04.011	Review.	The study provides an overview of research done on injury prevention and injury rehabilitation using XR in (elite) sports. XR is found to be useful for rehabilitation, but injury prevention is not improved by using XR technologies.
Stinson, C., & Bowman, D. A. (2014). Feasibility of Training Athletes for High-Pressure Situations Using Virtual Reality. *IEEE Transactions On Visualization And Computer Graphics*, *20*(4), 606–615. https://doi.org/10.1109/tvcg.2014.23	Specific application testing.	A CAVE-system is developed to practice goalkeeping in a stadium with crowd. The study finds that anxiety can be induced by such method.
Wirth, M., Mehringer, W., Gradl, S., & MEskofier, B. (2022). Extended Realities (XRs): How Immersive Technologies Influence Assessment and Training for Extreme Environments. In *Springer eBooks* (pp. 309–335). https://doi.org/10.1007/978-3-030-96921-9_14	Review.	Overview and definitions are provided for the main concepts of XR, with a focus on elite sports. Suggestions are given for hardware, software, and general considerations for

		future development.
Yasumoto, M. (2023). Bow Device for Accurate Reproduction of Archery in xR Environment. *Lecture Notes in Computer Science*, 203–214. https://doi.org/10.1007/978-3-031-35634-6_15	Specific application testing.	Hardware and software is developed for the VAIR Bow v3, which allows for archery practice and eSport matches in an XR environment. It uses a physical bow, but no arrows.
Zhao, J., Mao, J., & Tan, J. (2022b). Global trends and hotspots in research on extended reality in sports: A bibliometric analysis from 2000 to 2021. *Digital Health, 8*, 205520762211311. https://doi.org/10.1177/20552076221131141	Review.	Literature is analysed. Main themes found are "(i) sports games and extended reality systems, (ii) virtual simulation devices and artificial intelligence, (iii) sports training and performance and (iv) age-appropriate physical activity, sports rehabilitation and physical education." The research is fragmented, thus more research is required to create stronger findings.

Table 11. Existing Applications in the Meta Quest Library (indicative list)

Name	**Used for**	**Usability**
VRFS – Football Simulator	Playing football	Low. Uses hands to play rather than feet.
VRLegs	Parkour	Medium. Enhances balance and coordination but limited by the lack of real physical movement.
BoxVR	Boxing fitness	High. Provides cardio workouts and improves reaction times and technique through virtual boxing drills.
Thrill of the Fight	Boxing simulation	High. Offers realistic boxing simulations that can enhance training, footwork, and timing.
FitXR	General fitness	High. Includes boxing, dance, and HIIT workouts that are effective for general fitness and sports conditioning.
Rezzil Player 22	Football training	High. Uses motion tracking to improve skills, reaction time, and cognitive abilities relevant to football. Includes goal keeping and ball-throwing simulator.
Eleven Table Tennis	Table tennis	Medium. Improves hand-eye coordination and reaction times, but lacks full-body engagement. Possible in virtual or mixed reality, and allows for online multiplayer matches.
Supernatural	Full-body workouts	Low. Provides guided workouts across various sports-like activities, improving overall fitness and agility. Lacks sport specific applications.

Holopoint	Archery and agility training	Low. Trains hand-eye coordination and agility. It is a game, in which archery is used. Different than how the sport of archery is practised.
Racket: Nx	Racket sports	Low. Engages users in a high-intensity racket sport simulation that improves agility, reflexes, and coordination. Is not representative of real racket sports.
The Climb	Outdoor climbing	Low. Attempts to simulate climbing experience, but crucial elements (strength required to hold grips, route finding) are not integrated well. Unrealistic capabilities ('jumping' from wall to wall).
Tennis Esports	Tennis	Medium. Simulates playing tennis, and includes gamification elements to practice skills. Ability to play online against other players. Physics and important elements (the angle at which a racket is held) are not completely consistent with the real world.

Table 12. Application Developers (indicative list)

Name	**Description**	**Sports**	**Specificity**	**Main product/service**
Reflexion	Develops cognitive training tools using VR to improve reaction times and decision-making skills	Various sports	Focus on cognitive and neuro-fitness training	N/A
Strivr	Provides VR training solutions to enhance athletic performance and mental preparation, and corporate training	American football, baseball	Immersive training for professional and amateur athletes	Corporate training solutions (e.g., Walmart)
Rezzil	Uses VR to train and rehabilitate athletes, focusing on cognitive and physical performance	Soccer, basketball, football	Cognitive and physical performance training and rehab	N/A
RideOn Vision	Develops augmented reality goggles for skiers and snowboarders	Skiing, snowboarding	AR goggles providing real-time data and navigation	N/A
Babolat	Produces smart sports equipment with sensors for performance tracking	Tennis	Smart racquets and equipment with performance analytics	Mainly known for producing traditional tennis equipment
Beyond Sports	Uses VR and AI to simulate game scenarios for tactical training	Football, basketball, American football	Tactical training using VR simulations	Visualizing positional player data.

Appendix B: interview guide

Introduction

- Introduce self
- Explain the aim of the study
    - Research current state of XR in performance sports organisations.
    - Research challenges and facilitators for XR adoption in performance sports organisations.
- Discuss confidentiality (person anonymous, organisation participation not)
- Explain structure of the interview
    - Basic questions about participant and organisation
    - Current usage of XR
    - Perception of technology of XR
    - Perception of the organisation
    - Perception of the organisational environment

Basic questions

- What is your name, age, function, and amount of time you have worked for the organisation? Any previous experience within the sports industry?
- Are you familiar with the concept of extended reality?

Current usage of XR

- Can you describe where in the organisation XR is used?
    - Who is involved with it?
    - How long has your organisation used XR-technology?
    - Based on literature, I have categorized XR-usage for sports in seven categories. Which ones apply to your organisation's usage?

Perception of technology of XR

- Are you noticing any effects from the XR usage within the organisation?
- Were / are there any issues in implementing XR?
    - Have you had to change athlete trainings or employee-roles to implement XR?
    - If yes, does that happen often when you implement something new?
- How is the hardware (the HMD) perceived?
- How is the software perceived?

Perception of the organisation

- Do you have budget available for (technological) innovations?
    - Financial budget
    - Time budget
    - What are other examples, besides XR, where you have used technology to innovate in the last few years?
- Is there a specific person who is responsible for the XR implementation?
    - Did someone specific introduce the technology?
    - How does the top management feel about XR?
- General questions about organisation:
    - How are employees regulated in the way they do their job?
        - Are there many rules and regulations?
        - Are employees free to make their own decisions?
    - How do employees communicate and work with each other?

    - How do employees communicate and work with their supervisor? And vice versa?
    - Can you describe how the organisation is structured?
        - How many departments?
        - How many levels?

Perception of the organisational environment

- How do you perceive the pressure from other organisations to become better than you?
    - Do you need to keep innovating to maintain your current level, or even improve?
- Are other organisations, such as an app developer, involved in your XR usage?
    - Do they help you if there are problems?
- How is the government regulating how you use technology within your organisation?

Closing comments

- Is there anything else you wish to add regarding your organisation and/or XR usage?
- As promised, your organisation will be kept in the loop regarding any findings from the research.
- If desired, should direct quotes be used in the research, these can be submitted for approval. Do you wish for me to check this with you?
- Thank you for the participation.

Appendix C: participant consent form

The signed participant consent forms are available at the researcher.

Welcome and thank you for participating in this research study.

You are invited to take part in a research study titled ‘Implementation of extended reality technology in high-performance sports organisations’. This study is conducted in the context of a MSc. Thesis for the Business Administration study, of the Faculty of Behavioural, Management, and Social Sciences at the University of Twente. The researching student is Stijn Lagrand. The purpose of this study is to identify facilitators and inhibitors of extended reality usage at performance sports organisations, and to map the current state of the industry regarding extended reality usage.

Your participation is crucial to gain insights from the industry in this area. The information you provide will be solely used for research purposed and will be kept confidential. This interview will be conducted in a semi-structured format, which means that some questions have been prepared but open discussion is encouraged. Your responses and identity are kept completely confidential. Any identifying information will be removed or anonymised during the transcription process. The name of your organisation will not be kept confidential, as this is required to conduct the full case study of the organisation. The audio recording of the interview will be deleted as soon as the transcription process is complete, or by February 1st 2025, at the latest.

Your participation can contribute to a deepened understanding of extended reality adoption, and even technological adoption in general. Your organisation will be informed of the findings of the study, potentially providing you with useful information regarding extended reality usage.

The principal researcher can be contacted at s.lagrand@student.utwente.nl for any questions or concerns about participating in this study. By signing this form, you agree that you participate in this study voluntarily. You have a right to withdraw at any point during the study, or refuse to answer a specific question, without having to provide a reason. Additionally, you acknowledge that you are minimum 18 years old.

Participant name: Participant signature: