CHIARA COMPAGNONI

SLIDING SIMULATOR

Development of a sliding sports simulator ahead of the 2026 Milano-Cortina Winter Olympics

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Author: Chiara Compagnoni (247634)
Supervisor: Mario Covarrubias
Co-Supervisors: Marco Tarabini, Carol Sergenti

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ABSTRACT

Bobsleigh, skeleton and luge are sliding sports in which athletes with great strength, coordination and concentration descend at high speed along an icy track. However, limited track availability and the seasonal nature of these sports reduce training opportunities, making it difficult to maintain skills such as memorising and anticipating the track's geometry. In this context, simulators are a strategic solution that enable year-round training.

This thesis outlines a project that enhances the capabilities of existing simulators by incorporating cognitive and dual-task elements into the training environment. The designed exercises stimulate attention, memory and anticipation skills, enabling athletes to enhance their technical performance and mental preparedness in high-pressure situations. The system was also designed to support professional athletes in preparing for the 2026 Winter Olympics in Milano-Cortina.

The three-dimensional environment, based on the Cortina Sliding Centre track, was created as accurately as possible, despite being developed before the construction work was completed, while the interface was developed through a user-oriented design process and refined through user testing sessions, ensuring smooth navigation and high performance.

Overall, the project demonstrates how interaction design, integrated with real-time simulation, can generate immersive and cognitively stimulating training tools capable of reproducing competition conditions that are difficult to replicate in the real world.

SOMMARIO

Il bob, lo skeleton e lo slittino sono sport invernali in cui gli atleti, con grande forza, coordinazione e concentrazione, scendono ad alta velocità lungo una pista ghiacciata. Tuttavia, la disponibilità limitata di piste e la natura stagionale di questi sport riducono le possibilità di allenamento, rendendo difficile mantenere abilità come la memorizzazione e l'anticipazione della geometria del tracciato.
In questo contesto, i simulatori emergono come una risorsa strategica, capace di garantire opportunità di allenamento in ogni periodo dell'anno.

La tesi presenta un progetto che amplia le potenzialità dei simulatori esistenti introducendo componenti cognitive e dual-task nell'ambiente di allenamento. Gli esercizi progettati stimolano l'attenzione, la memoria e la capacità di anticipazione, consentendo agli atleti di migliorare l'esecuzione tecnica e la prontezza mentale in situazioni di stress.
Il sistema è stato inoltre progettato e sviluppato per supportare i piloti professionisti nella preparazione alle Olimpiadi invernali di Milano-Cortina 2026.

L'ambiente tridimensionale, basato sulla pista del Cortina Sliding Centre, è stato realizzato nel modo più accurato possibile, nonostante sia stato sviluppato prima del completamento dei lavori di costruzione, mentre l'interfaccia è stata sviluppata tramite un processo di progettazione orientato ai bisogni dell'utente e perfezionata attraverso sessioni di user testing, garantendo una navigazione fluida e prestazioni elevate.

Nel complesso, il progetto dimostra come l'interaction design, integrato con la simulazione in tempo reale, possa generare strumenti di allenamento immersivi e cognitivamente stimolanti, capaci di riprodurre condizioni di gara difficilmente replicabili nel mondo reale.

1.

INTRODUCTION

This chapter contextualises the project within the field of sports simulation, outlining how simulators facilitate safe, repeatable and data-rich training. It emphasises the role of UX/UI in achieving realism and facilitating learning, advocating for user-centred, perceptually credible interfaces. After introducing bobsleigh, skeleton and luge, the chapter focuses on the aspects of bobsleigh, the perception of pilots and the roles of the team, tracing the key historical and technical regulations. Finally, the chapter maps the structure of the thesis, which aims to merge virtual environments, interaction design, and cognitive tasks to support decision-making and year-round training for the pilots in preparation for the Milano-Cortina 2026 Olympics.

1.1 SIMULATORS AND THEIR USE IN SPORT

Sport is deeply embedded in human culture and everyday life. Beyond competition, sport is useful for self-improvement, fostering social connections, maintaining physical health, and promoting mental balance. Whether pursued by professional athletes, amateurs or ordinary individuals, sport supports personal growth, discipline and well-being, thereby contributing to individual and collective health.

In recent years, technology has transformed the way sport is practised, analysed and experienced. From data-driven training programmes to wearable sensors and immersive environments, digital tools have become indispensable for athletes and coaches alike. Among these innovations, simulators are a particularly transformative technology. They provide safe, repeatable and measurable training experiences that would otherwise be limited by time, space or physical risk. By reproducing the dynamics of movement and decision-making in a controlled environment, simulators enable athletes to refine their technique, improve their cognitive performance and engage in training that goes beyond what is possible on a real field (Neumann et al., 2018).

Over the past decade, simulators have become integral to sports science and performance research, bridging the gap between real-world practice and controlled experimentation. These systems, which range from virtual reality environments to motion-based mechanical rigs, allow researchers and coaches to replicate and manipulate complex sporting scenarios (Richlan et al., 2023). Systematic reviews confirm their growing relevance. For example, Yunchao, Mengyao and Xingman (2023) found that simulation technologies can effectively reproduce real-time decision-making processes and serve as valuable tools for assessing athletes' cognitive abilities. Similarly, Farley, Spencer and Baudinet (2020) noted that VR is increasingly being used in professional sports to gather physiological data, strengthen sensorimotor coordination and foster rapid response skills. Neumann et al. (2018) observed that virtual environments allow athletes to train independently of weather conditions and with full control over variables.

Immersion technology, considered an advanced form of digital interaction, has now become a central component of this transformation. Although already well established, it is drawing renewed attention as it continues to reshape how learning and training are accomplished in the modern world. Immersive systems operate by replacing sensory input from the external environment with digital sensory feedback generated by a computer, such as visual and auditory stimuli (Freina et al., 2015).

When users engage with immersive technology, they experience a strong sense of presence within the virtual environment and react to it as their brain and nervous system would in comparable real-world circumstances. This capacity to evoke genuine perceptual and physiological responses makes immersive simulation a powerful tool for both cognitive and motor training, bridging the boundary between physical experience and digital representation (Dewan et al., 2023).

At their core, simulators are computer-based systems that model real-world processes for design, analysis and learning purposes. They can be broadly classified into four main categories, each offering a different level of immersion and a distinct set of advantages.

1) *Screen-based simulations* consist of desktop or console systems that replicate training environments on a flat display. Although less immersive, they offer a cost-effective and flexible platform for tactical and perceptual learning, particularly when combined with motion tracking or haptic feedback devices;

2) *Large LED-wall or projection-based systems* provide a semi-immersive environment by surrounding the user with large-scale, curved or panoramic displays. These configurations enable a greater sense of spatial awareness and motion perception while maintaining visual comfort and accessibility;

3) *CAVE (Cave Automatic Virtual Environment)* systems provide a fully immersive spatial experience within cubic rooms whose walls serve as stereoscopic projection screens. CAVE systems enable athletes to perceive motion and depth cues similar to those experienced on the field while ensuring safe and controlled conditions;

4) *Extended Reality (XR)* encompasses *Virtual Reality (VR)*, *Augmented Reality (AR)* and *Mixed Reality (MR)*, combining physical and virtual worlds into interactive, three-dimensional experiences. XR systems are now among the most widely used tools for cognitive and motor training as they strike a balance between immersion and feedback.

Each of these categories contributes to a new learning paradigm in sport, merging physical and digital environments to create hybrid spaces for exploration and self-assessment.

Simulators support independent training and learning, while reducing the risk of injury and improving efficiency by providing precise, repeatable conditions. They also facilitate the collection and analysis of large amounts of performance data, paving the way for personalised and adaptive training.

1.2 UX/UI DESIGN FOR SPORT AND SIMULATORS

The design of the user experience (UX) and user interface (UI) in the field of sports and simulators is a critical factor in determining the effectiveness, realism, and overall value of the system.
In this domain, interaction design must be considered as a concept that extends beyond the realms of aesthetics or usability. Indeed, it has been demonstrated that interaction design has the capacity to shape how athletes, coaches and other relevant stakeholders perceive, interpret and respond to digital environments.

Simulators must strike the right balance between immersive realism, responsiveness, clear feedback and ergonomic usability, often under physically and cognitively demanding conditions (Bideau et al., 2010). A poorly designed interface has the potential to induce cognitive overload, disorientation, or even simulator sickness, thereby diminishing the potential benefits of training.

Therefore, a deep understanding of user needs and the physical and cognitive demands specific to each sport is essential for designing effective interfaces. Tailoring the UI to an athlete's abilities, motor skills and mental workload ensures that the simulator supports rather than distracts from the sporting task. This requires a user-centred research process based on observation, prototyping, usability testing and ongoing feedback (Gaspar-Figueiredo, 2023).

A further fundamental challenge resides in the differentiation of information flow and representation according to the target audience. Athletes require interfaces that facilitate direct data transmission to their body and technique; coaches benefit from mobile or analytical tools that enable real-time performance monitoring and feedback; while fans require visualisations that are engaging and accessible. Designing for these diverse user groups demands adaptable systems that can adjust the depth, focus, and modality of information delivery.

From a perceptual standpoint, maintaining credible visual realism is equally important. Since sporting performance relies on precise spatial and temporal perception, the visual feedback provided by simulators must closely mirror real-world cues, minimising latency and distortion. This is particularly important in immersive AR/XR environments, where factors such as occlusion, motion synchronisation and visual hierarchy can directly impact decision-making and immersion (Pagé et al., 2019).

Simulator systems are also evolving beyond the mere replication of

physical motion to encompass natural and intuitive interactions that mirror real-life bodily movements (Kang et al., 2013). This includes personalised exercise modes and pose recognition techniques that adapt dynamically to the user's movements.

As interpreting perceptual stimuli from multiple sources becomes central to the simulator experience, the interaction designer plays a pivotal role as a mediator between technological development and human experience. Beyond creating functional interfaces, designers operate at the intersection of sensing, cognition and embodiment. They translate streams of sensory data into meaningful and intuitive feedback that guides users' perceptions and actions (Calleo et al., 2023).
In the context of sports simulators, this involves designing for more than just accuracy or realism; it involves designing for learning through perception, enabling athletes to internalise complex dynamics and react instinctively within controlled, lifelike environments. The interface thus becomes a crucial layer of mediation, shaping how technology communicates with the body and how athletes and coaches perceive, feel and learn to move and make decisions within virtual spaces.

1.3 INTRODUCTION ON BOBSLEIGH, SKELETON AND LUGE

Bobsleigh, skeleton and luge are collectively known as ice sliding sports. They are characterised by the use of gravity-powered sleds travelling at high speeds on artificially refrigerated ice tracks comprising straights, curves and labyrinth sections (Hubbard, 2013).

While all three disciplines share the fundamental principle of sliding on ice, they differ in terms of the equipment used, the techniques employed and the body positions adopted. In luge, athletes lie on their backs and steer using subtle leg and shoulder movements. In skeleton, competitors descend head-first and control their speed through subtle shifts in body weight (Sabbioni et al., 2015). In bobsleigh, meanwhile, teams of two or four athletes tackle the descent on the icy track in a seated position aboard an aerodynamically optimised sled, which is guided by ropes positioned inside.

While each sport has its own unique characteristics, this thesis focuses on bobsleigh, since the developed project and simulator are primarily designed around this discipline.

To frame and deliver this part of the research, two main research questions have been proposed:

1) *What are the fundamental aspects of bobsleigh?*
This question focuses on the technical aspects of the sport, including sled design mechanics, driving techniques, and external performance influencing factors such as weight and aerodynamic;

2) *What does the pilot perceive during a run, and what actions are required to control the sled?*
This question looks at the pilot's role in bobsleighing by examining the sensory stimuli they are exposed to and how these perceptions influence their driving strategies.

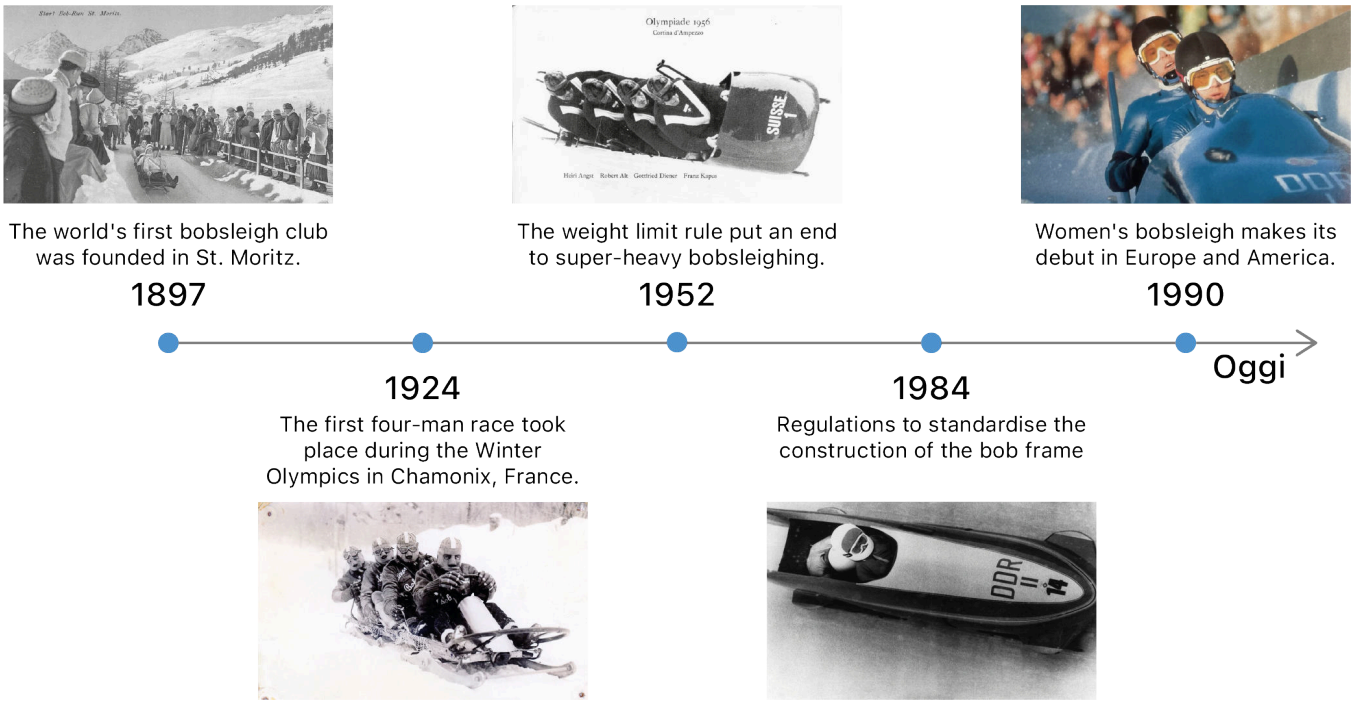
By articulating these research questions, the research aim to introduce and explain the technical and perceptual dimensions of bobsleigh, providing a foundation for subsequent analysis and simulation-based design interventions.

1.3.1 History of Bobsleigh

The origins of bobsleigh can be traced back to late 19th-century in Switzerland. In the Alpine resort of St. Moritz, wealthy tourists began modifying traditional wooden sleds to make them steerable and faster, thus transforming a leisure activity into a competitive pursuit.
This pastime soon evolved into an organised sport, and the first official bobsleigh club was founded in St. Moritz in 1897 (IBSF, n.d.).

The construction of the first dedicated ice tracks in the early 1900s was a decisive step in establishing the sport's competitive identity.

Fig.1: Bobsleigh history timeline



It then made its Olympic debut in 1924 at the Winter Games in Chamonix with the four-man event, followed by the introduction of the two-man race at Lake Placid in 1932 (IBSF, n.d.).

A major turning point came in 1952 when maximum weight limits for sleds and crews were introduced to ensure fairer competition by standardising equipment performance. Further regulations introduced in 1984 defined permissible materials and construction techniques, establishing the framework for the highly engineered sleds used today.

1.3.2 Technical characteristics of bobsleigh

The International Bobsleigh & Skeleton Federation (IBSF) enforces strict regulations regarding sled construction, dimensions and maximum weight, as heavier sleds tend to reach higher speeds
Modern bobsleigh sleds are the result of collaboration between engineers, manufacturers and athletes, combining aerodynamic design with lightweight and resilient materials (Wacker et al., 2006).

The races start with a push phase, during which the sleds reach speeds of between 130 and 145 km/h. Sleds experience forces of up to 5 g in certain curves (Hubbard, 2013). The driver steers via two ropes connected to the front frame, making minimal angular adjustments, often less than 5°, that require great precision given the low friction coefficient between runners and ice (Sabbioni et al., 2015) (Fig. 2).

Braking only occurs after crossing the finish line, when the brakeman deploys a claw into the ice.

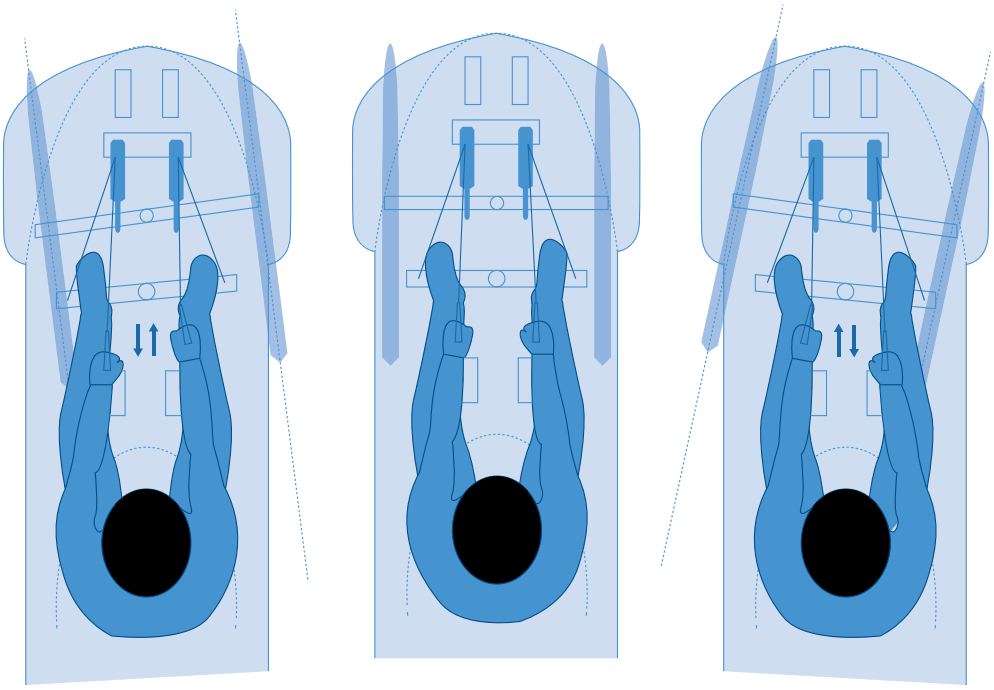
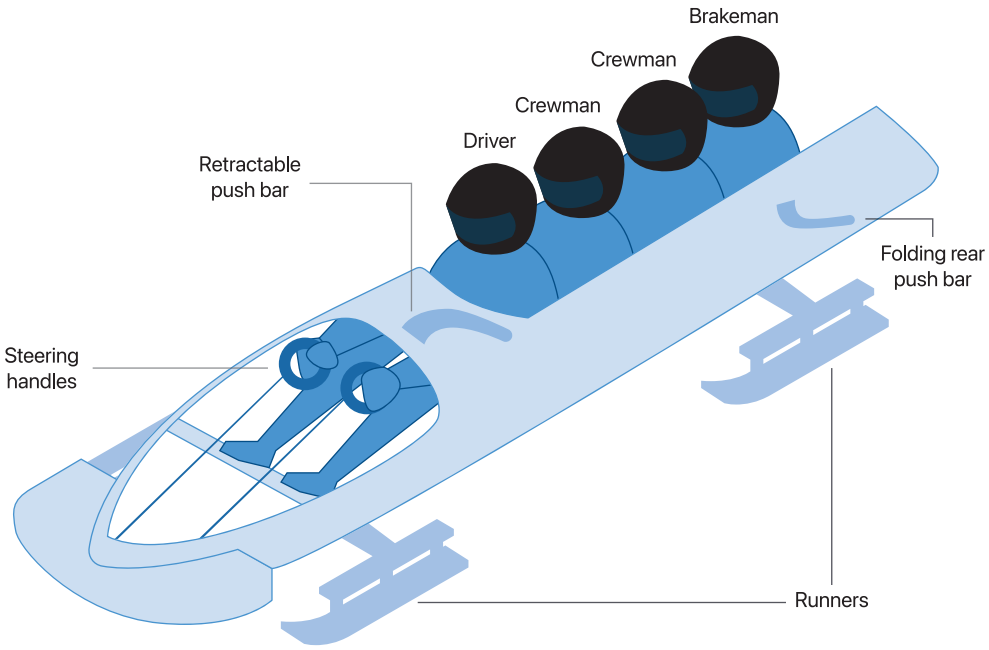


Fig.2: Sled control on the track. Bobsleight steering system. (IBSF | International Bobsleigh & Skeleton Federation: Bobsleigh, n.d.)

Fig.3: How bobsledding works, sled overview



1.3.3 Athletes

Each bobsleigh team comprises athletes with different roles (Fig.3). The driver is the leader and technical core of the team and is responsible for steering the sled. This demanding role requires exceptional spatial awareness, fine motor control and the ability to make tactical decisions under extreme pressure.

At the start of each run, the push athletes generate the initial acceleration by sprinting on the ice. This initial acceleration is crucial, as it determines the maximum speed and optimal trajectory achieved during the run (Sabbioni et al., 2015). After crossing the finish line, the brakeman activates the brake to ensure a controlled stop (IBSF, n.d.).

Interestingly, only the driver has a complete view of the track during descent, while the other team members must rely entirely on timing, rhythm and mutual trust. It is this interdependence that transforms bobsleigh from an individual act of control into a deeply coordinated collective performance.

1.3.4 Track specifications

Olympic tracks adhere to rigorous international standards.
They range in length from 1,200 to 1,650 metres, with an elevation drop of 110–125 metres. They must also include at least 14 turns, as well as specific features such as a labyrinth (a sequence of three rapid curves) and a straightaway. Tracks are designed to enable sleds to reach speeds of 80–100 km/h within the first 250 metres.
To ensure safety, centrifugal forces are limited by regulations:

a maximum of 5 g is permitted, but only for very short periods (Hubbard, 2013). Sidewalls, gradients and construction dimensions are standardised, with maximum slopes capped at 12% (Mössner et al., 2011).

Modern artificial tracks are carefully engineered to combine technical challenge with safety, requiring complex simulations and biomechanical studies during the design phase (Mössner et al., 2011).

For athletes, navigating such tracks poses an extreme physical and mental challenge as the combined forces of gravity, centripetal acceleration, friction and aerodynamic drag demand precise steering and exceptional resilience (Sabbioni et al., 2015).

1.4 SENSATIONS AND STIMULI PERCEIVED BY THE PILOT

Driving a bobsleigh requires extreme multisensory coordination. The pilot must integrate diverse streams of sensory information while under high physical and cognitive stress. Each descent is a complex perceptual event in which vision, balance, touch and sound must be continuously interpreted and translated into rapid motor actions.

Of all the sensory inputs, vision is the most dominant, accounting for around 70% of motion-related information processing. Through visual cues, the pilot can anticipate the curvature of the track, the entry and exit of turns, and the sled's alignment (Hubbard, 2002).

Peripheral vision is important for detecting motion flow and maintaining orientation, while foveal vision focuses on specific reference points. Experienced pilots often rely on external visual markers, such as poles, trees, shadows or lamp posts alongside the track, to anticipate upcoming sections and time their steering inputs with millisecond precision.

Beyond sight, the vestibular system of the inner ear provides the pilot with essential information about angular acceleration, tilt and balance. During a run, the body experiences accelerations in all three spatial directions, with rolling motion (rotation around the sled's longitudinal axis) being the most intense and disorienting (Hubbard, 2002).

The pilot must maintain spatial orientation while enduring up to 5 g of force for short periods. Such forces can cause a temporary loss of visual acuity and affect proprioceptive awareness, so the ability to read subtle shifts in motion is a crucial skill that is developed through extensive experience and muscle memory (Hubbard, 2002).

Tactile perception is another fundamental sensory layer.
Steering is performed via two ropes connected to the front runners, which transmit vibrations and resistance directly to the pilot's hands (Fig. 2). The tension in these ropes provides a constant flow of haptic information about the sled's contact with the ice. A skilled pilot can detect even the slightest variations in pressure and friction, adjusting their inputs accordingly to maintain an optimal trajectory.

Finally, auditory stimuli contribute to the overall sensory landscape.
The roar of the runners on the ice, the wind pressure inside the helmet and the acoustic resonance of the sled provide an additional channel of feedback. Many pilots report using subtle changes in sound pitch and rhythm to sense their speed or detect when the sled is drifting.

Together, these multisensory signals form a dense and dynamic flow of information that the pilot must interpret in real time.
The challenge lies in maintaining control not through conscious thought, but through embodied cognition, the deeply trained capacity to act instinctively based on sensory feedback.

From a simulator's perspective, accurately reproducing multisensory cues in a controlled environment is essential for achieving realism and enabling as much perceptual learning as possible to be transferred from simulation to the actual track.

1.5 PROJECT CONTEXT AND HARDWARE DESCRIPTION

Disciplines such as bobsleigh, skeleton and luge are characterised by a scarcity of training opportunities. The number of tracks worldwide is limited, and their use is restricted by seasonal, logistical and financial constraints. In Italy, for example, athletes have access to only a few tracks and can only train under specific conditions during the winter months. Consequently, the national team often relies on international facilities abroad, incurring high travel costs and facing limited access to consistent training sessions.

This lack of accessibility poses a significant challenge to athletes, whose performance hinges on their ability to memorise, visualise and anticipate the precise contours of each track.

Unlike in other sports, where technique can be refined through repetition, sliding athletes primarily rely on spatial and visual memory, supported by mental focus and split-second decision-making.

Therefore, maintaining these cognitive skills throughout the year, even without direct access to the track, has become one of the main priorities for teams and coaches.

In response to this, the project proposes the development of an interactive simulation system designed to recreate the sensations experienced by athletes during a bobsleigh descent.

The simulator enables athletes to train on virtual reproductions of real tracks, such as the Cortina Olympic track, at any time of year.
Offering more than just visual playback, it provides active control over the sled's steering, enabling users to explore different trajectories, test strategies and experiment with varying conditions. In addition to its physical element, the project comprises three training exercises designed to enhance cognitive abilities such as attention, reaction time and memory, essential mental skills for high-speed sports.

During the simulation, athletes perform focused tasks integrated into the descent, testing their ability to remain alert and make accurate decisions under pressure. This combination of physical control and mental engagement transforms the simulator from a technical prototype into a comprehensive training platform that mirrors the complexity of real-world performance.

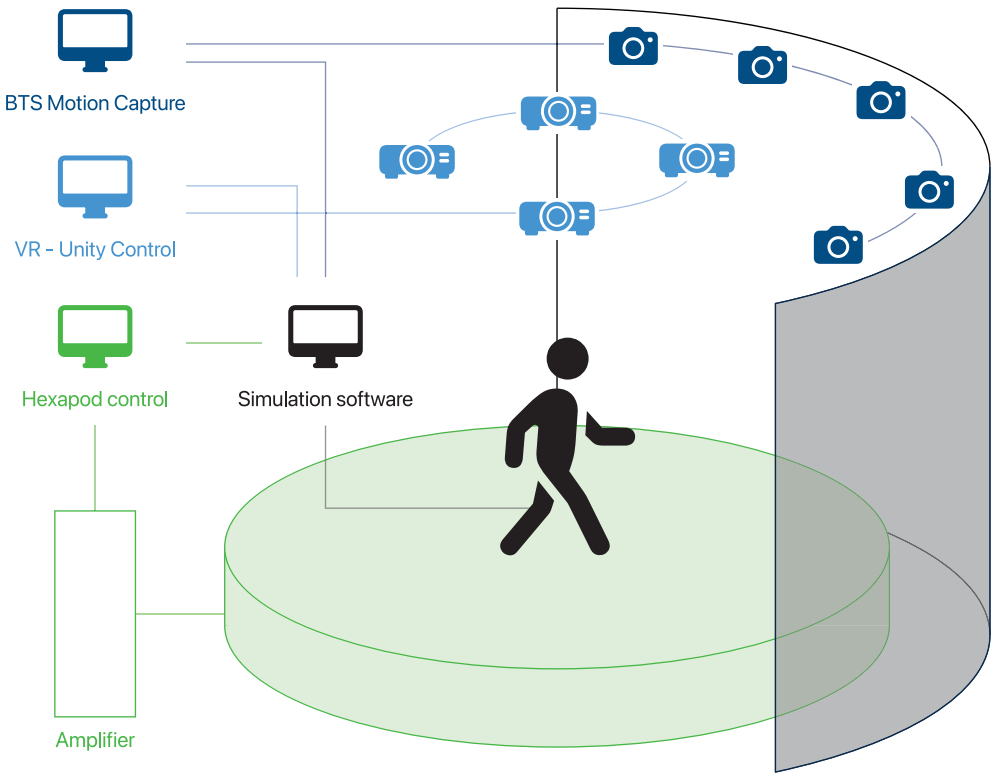


Fig.4: Scheme of Hexalab system contol and measurement systems. (Sergenti et al., 2024)

This integration reflects the growing awareness in contemporary sports science that mental readiness, perceptual acuity and the ability to process information under pressure are as important as physical training in achieving excellence at an elite level.

Although the system was initially conceived as a multidisciplinary sliding simulator, the design process has increasingly focused on bobsleigh. Nevertheless, the simulator's modular architecture remains adaptable, allowing it to be extended to other sports, such as skeleton and luge.

From a technical perspective, the simulator was developed by integrating several software tools. Figma was used to design and test the interface prototypes, Unity was used as the primary environment for simulation, interaction logic and data visualisation, while Blender was used for modelling and modifying 3D track geometries.

The resulting software application is designed to run within Hexalab, a high-performance research infrastructure dedicated to immersive simulation and human–technology interaction. Hexalab's architecture includes a six-degree-of-freedom (6-DoF) parallel kinematic robotic platform that can reproduce complex motion patterns; an immersive curved projection screen for spatial visualisation; a simulation control software; and a motion capture system (Fig. 4).
Its modular configuration allows for the integration of multiple technologies, including optical tracking systems, load cells, wearable sensors and haptic devices such as treadmills. An integrated audio system complements the visual and physical components, contributing to an immersive, synchronised environment suitable for experimental research and training (Sergenti et al., 2024).

The simulator has two main user interfaces, each supporting a distinct role in the training process. These are described in detail in *Chapter 5*. The athlete interface provides access to the virtual environment and cognitive exercises, prioritising clarity, responsiveness, and intuitive control. The administrator interface, which is accessed from a separate computer, allows coaches and researchers to manage user profiles, select tracks, configure exercises and monitor performance data.
This dual-interface architecture promotes collaboration between athletes and coaching staff, facilitating personalised training sessions and data-driven feedback loops.

Although the system was designed for use within Hexalab, its software and hardware architecture remain highly adaptable.
The simulator can be reconfigured for alternative setups, including with virtual reality headsets or smaller-scale motion systems, enabling deployment beyond laboratory conditions.

1.6 THESIS PURPOSE AND STRUCTURE

1.6.1 Thesis Purpose

This thesis explores the role of interaction design in developing simulation systems for sports training. It investigates how virtual environments, interface design and cognitive tasks can be integrated to improve athletes' perception, cognition and decision-making during training, thereby enhancing their performance in professional contexts.

At its core, the project addresses a critical gap in the training routines of sliding-sport athletes, who are severely limited by track availability, training frequency, and environmental conditions. The simulator provides a safe, repeatable, and data-driven virtual alternative that enables year-round practice while preserving the physical and cognitive complexity of real descents. It thus responds to the growing demand for accessible, high-fidelity training tools that can reproduce the physical, perceptual, and mental demands of high-speed sports.

From a design perspective, the thesis is situated at the intersection of technological innovation and human-centred design. It proposes a methodology in which interaction design acts as a bridge between physical simulation, cognitive engagement, and user experience. Through the integration of simulation systems, motion feedback, and cognitive exercises, the research demonstrates how digital design can facilitate embodied learning, multisensory coordination, and the automation of decision-making processes under pressure.

The project's practical objective is to develop a realistic and dynamic simulator within the Hexalab infrastructure to support professional athletes preparing for the 2026 Milan-Cortina Winter Olympics.
This simulator will integrate motion systems, 3D modelling and cognitive training exercises into a single, coherent environment. This interactive system will enable professional bobsleigh pilots to visualise, anticipate and rehearse the track in a dynamic and controlled environment, thereby enhancing their technical precision and cognitive readiness.
Meanwhile, coaches can manage training sessions, monitor performance data and adapt parameters to each athlete's specific needs.

1.6.2 Thesis Structure

The thesis is divided into eight chapters, each of which addresses a specific aspect of the research and development process.

The first three chapters establish the theoretical framework and outline the key concepts underpinning the project. These chapters explore the role of simulators in contemporary sports training, the importance of

UX/UI design in creating realistic and coherent virtual environments, and the cognitive processes involved in perception, anticipation and decision-making in bobsleigh. Together, these chapters provide the conceptual foundation upon which the simulator's design and implementation are based.

The subsequent chapters present the design process in detail, describing how theoretical insights were translated into practical design decisions. They cover the creation of the virtual environment, the development of the interface and interaction model, and the technical implementation within the Unity engine.

Chapter 1: Introduction
This chapter contextualises the project within the field of sports simulation, outlining how simulators facilitate safe, repeatable and data-rich training. It emphasises the role of UX/UI in achieving realism and facilitating learning, advocating for user-centred, perceptually credible interfaces. After introducing bobsleigh, skeleton and luge, the chapter focuses on the aspects of bobsleigh, the perception of pilots and the roles of the team, tracing the key historical and technical regulations. Finally, the chapter maps the structure of the thesis, which aims to merge virtual environments, interaction design, and cognitive tasks to support decision-making and year-round training for the pilots in preparation for the Milano-Cortina 2026 Olympics.

Chapter 2: State of the art
The first part of this chapter presents an overview of the current state of sliding-sport simulators for bobsleigh, skeleton and luge in both scientific and commercial contexts. It analyses each system in terms of its simulation hardware, virtual environment modelling and the types of tasks offered to athletes. The second part of the chapter focuses on contemporary case studies of simulator interfaces from different sports domains. These examples demonstrate various strategies for organising information, providing feedback, and adapting interaction to different user profiles. Together, the two sections lay the groundwork for the design principles that guided the development of the new simulator presented in this thesis.

Chapter 3: Training and cognitive tasks
This chapter examined the training routines of bobsleigh athletes, and explored the theoretical basis of cognitive tasks in sports training.
It then analysed cognitive and dual-task training methods in various sports, demonstrating how perception, anticipation and reaction times can be improved through specific exercises and interactive systems.
Finally, the chapter presented three cognitive tasks that have been integrated into the sliding simulator.

These tasks provide a structured framework for training repetition, visualization, and muscle memory in an immersive environment.

Chapter 4: Virtual environment
This chapter outlines the design and development process of the virtual environment employed in the simulator. First, it outlines the creation of a preliminary model based on the Cesana track. This model is used to test materials, lighting, and regulatory elements derived from IBSF standards. It then goes on to detail the modelling of the final Cortina Sliding Centre environment. This includes remeshing, and creating all structural, environmental and lighting components in Blender and Unity. Finally, the chapter covers the integration of interactive elements for the simulator's training exercises.

Chapter 5: Interface and interaction development
The chapter defines the simulator's UX from foundations to final screens. It introduces three personas that inform the requirements for a dual-interface setup: an immersive pilot point of view (POV) and a secondary control user interface (UI) for coaches/operators.
The information architecture organises the experience into four phases: Access and Onboarding, Training Experience, Performance Review and Statistics. These are supported by wireframes and a cohesive design system. The interface as a whole emphasises clarity, consistency and scalability, adapting to both novices and professionals while enabling data-driven coaching and long-term performance analysis.

Chapter 6: Implementation in Unity
This chapter outlines how the developed elements are implemented in Unity. It begins by explaining how a block diagram maps screens, actions and scripts, providing guidance for a Unity architecture that enables seamless navigation and performance.
It then details the implementation process, from Figma exports (sprites, fonts and 3D assets) to the organisation of the Unity project hierarchy. Scripts are explained and grouped into eight categories: Core, Service, Physics, UI, TrackRun, BubbleMemory, BlindCurves and History.
Finally, it provides a theoretical comparison of curved-screen and VR modes, highlighting their differing ergonomics, display constraints and calibration needs.

Chapter 7: Usability testing
This chapter outlines the user testing process and the subsequent design enhancements. Ten qualitative tests on mid-fidelity wireframes helped to validate the interaction flow, usability and clarity.
Based on user feedback and SEQ ratings, several refinements were made, including clearer navigation, improved visualisation of statistics, and revised interface logic for the profile and buttons.

Overall, the tests confirmed the design's usability, while also highlighting areas where greater clarity and accessibility could be achieved across different user categories.

Chapter 8: Conclusions
This chapter outlines the main achievements and future directions of the project. It summarises the design and development of a dynamic simulator for sliding sports that integrates physical realism with cognitive training in order to improve athletes' perception and decision-making abilities. The conclusions emphasise the innovative dual-interface structure of the simulator and the potential of interaction design to bridge the gap between technology, perception and athletic performance. Proposed future developments include improving environmental fidelity through 3D scanning, expanding to other disciplines, integrating adaptive AI systems and refining multisensory cognitive tasks.

2.

STATE OF THE ART

The first part of this chapter presents an overview of the current state of sliding-sport simulators for bobsleigh, skeleton and luge in both scientific and commercial contexts. It analyses each system in terms of its simulation hardware, virtual environment modelling and the types of tasks offered to athletes. The second part of the chapter focuses on contemporary case studies of simulator interfaces from different sports domains. These examples demonstrate various strategies for organising information, providing feedback, and adapting interaction to different user profiles. Together, the two sections lay the groundwork for the design principles that guided the development of the new simulator presented in this thesis.

2.1 EXISTING SLIDING SIMULATORS

In order to inform the design and development of the simulator presented in this thesis more effectively, an in-depth investigation was conducted into existing sliding sports simulators. This research aimed to understand the objectives and tasks of the solutions currently available on the market and in academic contexts, as well as how they approach the creation of virtual environments, modelling of tracks, and representation of surrounding elements.

The following section provides a chronological overview of simulators for bobsleigh, skeleton and luge, including scientific prototypes and commercial or entertainment-oriented systems.
For each simulator, the analysis focuses on three key aspects: the simulation hardware; the type of virtual environment developed; and the nature of the tasks offered to users.

By comparing these existing systems, the analysis will highlight the evolution of simulation technologies in sliding sports, identifying the gaps and opportunities that guided the development of the new simulator proposed in this thesis.

2.1.1 Bobsleigh Driving Simulator, Team Germany (La Plagne Track, France, 2002)

One of the earliest bobsleigh simulators was developed for the German national team in 1998. At the Olympic Training Centre (OSP) in Oberhof, it allowed pilots to familiarise themselves with track sequences, curve dimensions, and driving rhythms even during the off-season.

Practical evaluations carried out at the OSP Oberhof confirmed that the bobsleigh driving simulator was an effective training device for improving coordination and reaction times (Eule, 2001). By virtually reproducing runs on the Winterberg and Altenberg tracks and enabling athletes to control the descent, the simulator helped to train anticipation, fine motor control and adaptive skills. The pilot's point-of-view representation provided an immersive cognitive experience of each track's rhythm and sequence, aiding the memorisation and internalisation of driving patterns. The system was based on reconstructions of real bobsleigh tracks, created using survey data and construction blueprints.

2.1.2 Bobsled Simulator for Olympic Athletes, Team USA, (Salt Lake City Olympic track, Utah, Olympics 2002)

Designed to provide American pilots with an advanced tool for unlimited practice and performance analysis, this bobsled simulator was developed in preparation for the 2002 Winter Olympics in Salt Lake City.

Fig.5: On the left, Simulator 1st version (Sabbioni, 2015)

Fig.6: On the right, Simulator 3rd version (Sabbioni, 2015)





This simulator enables athletes to perform as many virtual descents as they wish, focus on specific sections of the track, practise on various courses, compare their trajectories with those of other drivers and receive quantitative feedback after each run (Sabbioni, 2015).

Combining advanced hardware and software for the age, the simulator reproduced the sensory complexity of bobsleigh driving by integrating visual, tactile, auditory and balance feedback.
It consisted of a fibreglass sled shell mounted on a mechanical frame that replicated the dimensions and ergonomics of an actual bobsleigh cockpit. Inside, athletes used a rope-based steering system modelled on real steering mechanics. A front monitor displayed the virtual track, while speakers reproduced the characteristic sounds of ice friction and aerodynamic flow to contribute to the realism of the experience (Hubbard, 2002) (Fig.5 & Fig.6).

From a modelling perspective, the track is represented as a sequence of transverse sections, which are then interpolated using cubic polynomials. The simulator assumes continuous contact between the sledge and the ice surface, using two coordinates to define the sledge's position: the distance from the start and the lateral distance from the right-hand track wall. This simplified yet precise representation allows dynamic calculations to be performed in real time.

2.1.3 Ride Training Simulator for Bobsleigh and Luge Drivers, Team Japan (Nagano Olympic track, Japan, 2006)

In 2006, Japan developed a new generation of training simulators for bobsleigh and luge athletes. These were designed to replicate the dynamics of real descents on the Nagano Olympic track. Both systems featured large projection screens and six-degree-of-freedom (6-DoF) motion platforms, enabling athletes to experience the movement, vibration and visual flow of the track in real time.

In the bobsleigh simulator, the athlete's point of view was projected onto a curved display made up of four large panels, while the motion

platform reproduced the dynamic motion of the sled based on real sliding footage (Miyao et al., 2002) (Fig. 7). To reinforce immersion, a pair of speakers positioned in front of the cockpit reproduced characteristic bobsleigh sounds to provide synchronised auditory feedback.

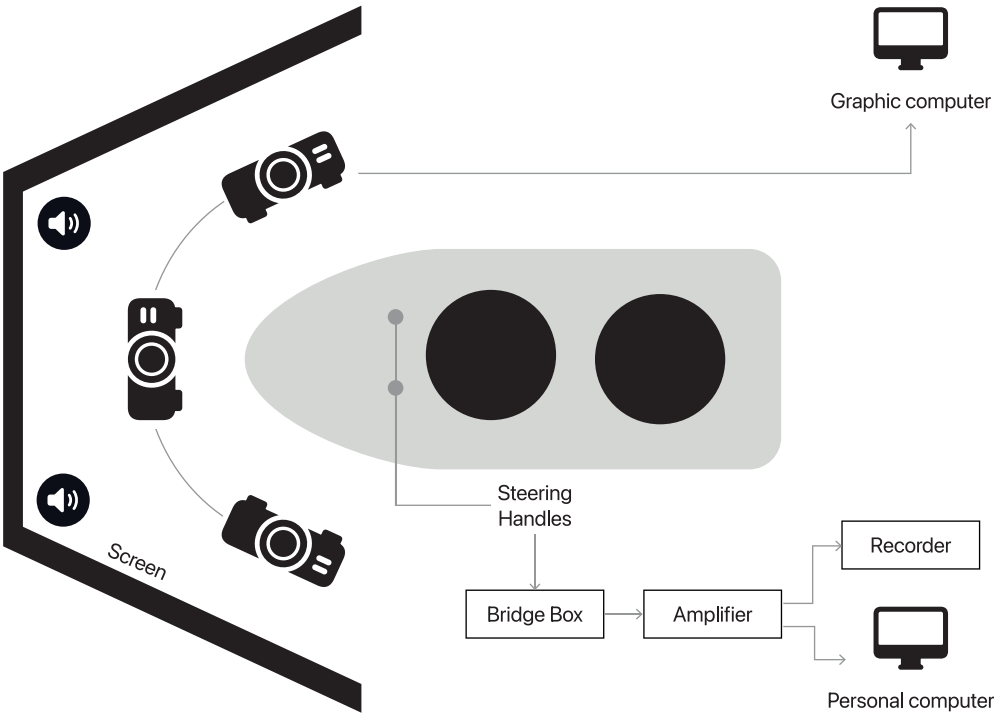
The simulation integrated visual reference points such as poles, cameras, and course markers, key cues used by athletes to memorise track sequences. Additionally, the system allowed adjustments to be made to the playback speed and camera height, enabling personalised training to be tailored to each athlete's viewpoint and preferred level of difficulty. By detecting weight shifts and body movements, the simulator reproduced the realistic interaction with the sled, creating an authentic training environment that closely approximated the sensations experienced on the track (Miyao et al., 2002).

Finally, the virtual environment was created using a combination of real recorded footage and a 3D computer-generated model of the surrounding landscape.

2.1.4 A Luge and Bobsled VR Simulator, University of Calgary (Salt Lake City Olympic track, Utah, 2007)

In 2007, researchers at the University of Calgary developed a virtual reality simulator for bobsleigh and luge. Designed to be highly portable and accessible, it was intended as a training tool. Unlike previous motion-based systems, this prototype kept the sled in a fixed position while

Fig.7: Hardware component description and visualization (Miyao et al., 2002)



the virtual environment moved around the athlete. This provided an innovative approach to perceptual and cognitive training (Katz, 2008).

The simulation was based on the 3D geometry of the Salt Lake City Olympic track, which was recreated in a CAD environment, and digital models of bobsleigh and luge sleds were used as selectable avatars. The visual rendering of the data was distributed across four synchronised screens, which displayed the athlete's point of view from a fixed onboard camera. This was similar to the perspective commonly used in race video analysis.

This fixed-camera setup offered multiple advantages. By eliminating the pilot's physical displacement, the simulator provided a stable and safe environment in which to learn the track layout and improve cognitive anticipation of curves. Athletes could practise anticipating turns at high speed, often before they were visible, while also training their ability to adapt to visual blur caused by motion (Sabbioni, 2015).

Additional features included an overlay guideline along the track displaying the optimal racing line, and a playback mode allowing athletes to compare their own trajectories with the ideal one.
The simulator also featured speed-dependent sound control, providing realistic audio feedback tied to sled velocity.

2.1.5 A Bobsleigh Simulator Software, Team Switzerland (Whistler Olympic Track, Canada, 2014)

The Swiss bobsleigh simulator was developed in preparation for the 2014 Winter Olympics in Sochi. It was created to analyse driving trajectories, evaluate sled dynamics and support athletes and track designers in improving performance and safety.

Based on the Whistler Olympic track in Canada, the simulator uses advanced physical modelling and real-time visualisation to accurately reproduce the dynamics of a bobsleigh descent (Rempfler et al., 2015).

It consisted of a two-man bobsleigh mock-up mounted on a fixed frame and equipped with a functional steering mechanism. Athletes sat inside the sled while a large projection screen in front of them displayed the reconstructed track environment (Rempfler et al., 2015) (Fig. 9).
Audio-visual feedback and physical calibration informed by the pilots made the simulation highly realistic and widely accepted among Swiss professional pilots.

The track model was digitally reconstructed from the official construction data for the Whistler track and a multi-body model of the bobsleigh was implemented to simulate realistic mechanical behaviour (Fig. 8).

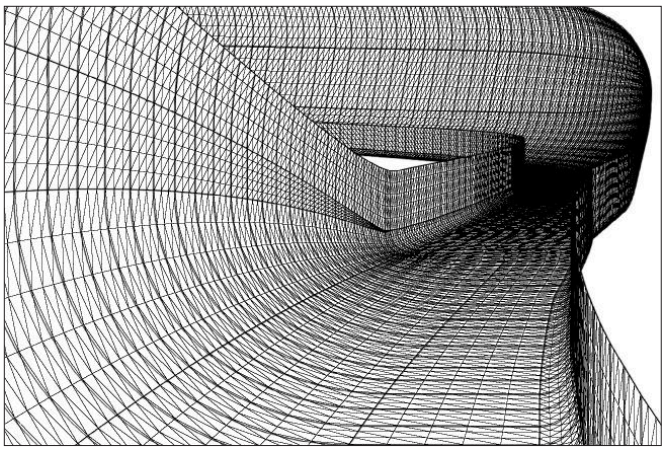




Fig.8: On the left, NURBS surface and its tessellation, the triangle mesh of the track (Rempfler et al., 2015)

Fig.9: On the right, simulator in the laboratory (Rempfler et al., 2015)

2.1.6 BMW Bobsleigh Simulator, Team Germany (Königsee Track, Germany, 2018)

Developed by the BMW Group in collaboration with the German national bobsleigh team, this simulator is one of the most advanced and realistic training systems ever created for sliding sports (Crane, 2023).

It consists of an original bobsleigh mounted on a four-degree-of-freedom motion platform surrounded by a 210° curved projection screen, which delivers a highly immersive visual experience. The platform reproduces the sled's motion, including pitch, roll and lateral acceleration, while a force-feedback steering system recreates the runners' mechanical response on ice (Bertera, 2022).

The virtual environment was created using laser scanning and 3D reconstruction of the Königsee Olympic track, which is used by the German team for training. This includes surface irregularities, ice textures and characteristic visual reference points, such as poles, barriers and lamps, which pilots commonly use for orientation and timing.
The digital environment is projected in real time onto the panoramic screen to simulate the sense of speed and rhythm of curves typical of

Fig.10: On the left, simulator setup (Bertera, 2022)

Fig.11: On the right, one athlete using the simulator (Bertera, 2022)





actual descents. Professional athletes contributed to fine-tuning the geometry of curves, reducing excessive sensitivity when clipping track walls and smoothing out unrealistic transitions (Bertera, 2022).

2.1.7 A Real-time Simulator for the Sport of Skeleton, Master's Thesis, TU Delft (Salt Lake City Olympic track, Utah, 2019)

This academic prototype provides a step-by-step documentation of a complete pipeline for the digital reconstruction and simulation of an Olympic ice track for real-time skeleton training and analysis.
Starting from a plan view of the Salt Lake City track, the author uses construction data such as curvature and elevation to recover the 3D centreline, splitting the course into straight and curved segments linked by clothoids to ensure smooth transitions. Cross-sections are then generated: a standard section is used for the straights and the curve sections are approximated using video frames of real runs and are then rotated and placed orthogonally along the centreline. To improve the geometric accuracy of the bends, additional sections are added using Bézier interpolation (Shankar, 2019).

2.1.8 Bobsleigh VR, Entertainment & Research (Nagano Olympic track, Japan, 2021)

This VR prototype was developed to preserve the sporting legacy of the Nagano Olympic track, as well as to explore sustainable tourism and indoor training. It focuses on reproducing the lateral sliding motion that greatly influences how bobsleighing is perceived (Ban et al., 2021).

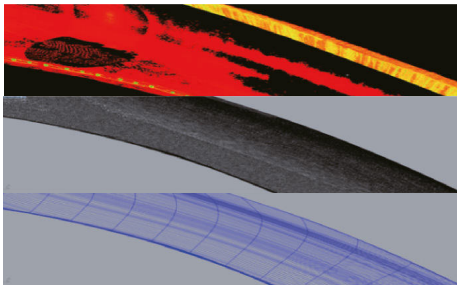
The setup combines a VR experience with a manually operated hammock: while the user views the run in real time, assistants swing the hammock to create inertial cues during cornering .

The track surface is automatically generated from accessible construction data, such as the centreline and cross-sectional shapes.
The resulting surface is tessellated into a triangular mesh that preserves sliding smoothness for real-time rendering in VR (Ban et al., 2021).

2.1.9 Immersive Skeleton Simulation System (VR), (Yanqing Olympic Track, Beijing, 2025)

This VR simulation system, was developed at the National Skeleton and Bobsleigh Centre in Beijing. It integrates laser-scanned track data, motion capture technology and a six-degree-of-freedom motion platform to provide a fully immersive, realistic training environment.

The Yanqing Olympic track was scanned using a Leica RTC 360 laser scanner to achieve a spatial accuracy of around 2 mm. The resulting point cloud included the track and the surrounding infrastructure.
Following cleaning and surface extraction, the dataset was processed



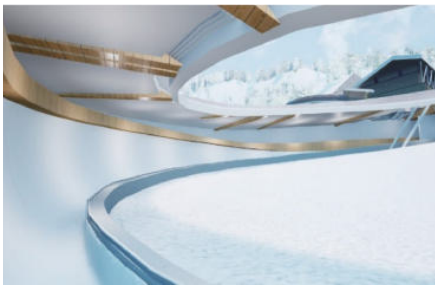




Fig.12: On the left, point cloud model, mesh model and smooth surface model (Wang et al., 2025)

Fig.13: In the centre, virtual environment of the National Sliding Centre (Wang et al., 2025)

Fig.14: On the right, simulation test (Wang et al., 2025)

in Rhino using meshing and surface fitting techniques to generate a smooth, continuous 3D surface. The refined model was then imported into Unreal Engine 4 (UE4), where global illumination, stadium lighting and ice textures were added to create a visually and spatially accurate virtual replica of the Olympic venue (Wang et al., 2025).

To simulate the athlete's control and posture, motion capture sensors were attached to 11 key points on the body. These sensors track the athlete's centre of mass in real time, enabling the simulator to translate shifts in body weight into steering actions. The 6-DoF motion platform responds dynamically to these movements, reproducing acceleration, tilt, and vibration with high fidelity (Wang et al., 2025).

Alongside the visual and motion components, a synchronised wind simulation system uses variable-speed fans to replicate air resistance according to sliding velocity, adding another layer of sensory realism.

Together, these elements enable athletes to practise steering, posture control and track memorisation under safe and repeatable conditions.

2.1.10 Conclusions

The comparative analysis of existing sliding simulators reveals a clear evolution in technological sophistication and training objectives over the past three decades. Early systems, such as those developed in Germany and the USA in the late 1990s and early 2000s, primarily focused on visual familiarisation and coordination training. These systems relied on fixed platforms and simple display technology to recreate the rhythm and geometry of the tracks.

From the mid-2000s onwards, the introduction of motion platforms and multi-screen or VR projection meant that simulators could integrate multisensory feedback, combining visual, auditory and motion cues to improve realism and immersion. Systems developed in Japan and Switzerland, and later by BMW for the German team, demonstrated how simulation evolved to enable the quantitative analysis of trajectories, driver feedback and safety evaluation.

The integration of multi-body physical models, real-time dynamics, and precise 3D reconstructions marked a turning point towards data-driven, experimentally validated training systems.

Advances in laser scanning, motion capture and VR technologies in recent years have enabled new simulators, such as those in Nagano and Beijing, to expand the scope of simulation beyond elite training. These technologies have demonstrated that they produce results in the long- and short-term practice and performance of all athletes when applied to this kind of sport.

A recurring theme across all examples is that the effectiveness of a simulator depends less on physical realism alone and more on the integration of sensory feedback, accurate track modelling and cognitive interactivity. This combination enables athletes to internalise track dynamics, refine their motor responses and train safely in controlled environments.

Another important takeaway is that none of these simulators included cognitive or dual-task exercises, although, as will be explained in more detail in *Chapter 3*, all professional sliding sports athletes need cognitive exercises to prepare for descending the track in real life.

2.2 CASE STUDIES OF SIMULATOR INTERFACES

A series of case studies on contemporary sports simulation systems was analysed in order to define the characteristics of the interface and interaction of the simulator developed in this thesis. The aim of this research was to understand how modern simulators translate physical performance into digital environments, and how interfaces mediate the relationship between users, technology, and virtual spaces.

Particular attention was given to the user groups defined for using the systems, the simulation hardware and how different systems structure visual feedback, organise information across multiple screens and integrate environmental modelling into the interactive experience.

The goal was to identify effective design strategies and provide insights that would inform the development of a training interface that is intuitive, adaptable and immersive.

2.2.1 Skill Drill: A multi-modal simulator interface

Skill Drill, developed by Foresight Sports, is a football simulation platform that allows athletes to practise kicking and passing drills

indoors within the confines of a single room (Fig. 16).

The core ambition is to replicate the perceptual and motor demands of real football scenarios, such as free kicks, penalties and corners, while providing the user with real-time feedback and analytics.
This is particularly interesting because it provides a comprehensive training environment that combines physical execution with perceptual and decision-making challenges.

The research team identified several target user groups for Skill Drill. The primary users of the simulation are soccer players of all ages, from youth to professional level. The secondary users are coaches and trainers, who may guide sessions, interpret data, or structure drills.
The simulator may also be adopted by teams, clubs, and institutions for use in training facilities and is also designed to be used for entertainment purposes. As these users vary in expertise and objectives, the interface design had to be accessible and clear, and capable of scaling in complexity (SKILL DRILL, n.d.).

The interface can be divided in:

Mode selection & Setup UI
This interface allows users to choose from the available game modes and select difficulty levels. The mode selection screen highlights the currently selected mode and shows descriptive text (Fig. 15).
It also enables the launch of the simulation.
The settings screens also allow customisation of player avatars (colours and jersey numbers), which are displayed in the game.

In-game HUD/status bar
During the simulation, a transparent HUD sits at the top of the screen to preserve visual space and maintain immersion. Key stats displayed include the score, the number of remaining kicks, a list of players and the 'up next' player. The HUD layout is also adjusted in different screen aspect ratios (4:3 or 16:9) (Fig. 17).

Player management interface
Within the in-game environment, a collapsible player dropdown menu allows players to be added or switched mid-session. The interface supports an unlimited number of players, accommodating group/party use.

Post-game/leaderboard interface
After completing a session, users see a leaderboard screen showing performance from the last game, as well as local and global rankings. Results and metrics are displayed side by side on the same interface. This interface is visible on a separate screen (Fig. 18).





Fig.15: On the top-left, clear and minimal homepage interface (Hale, n.d.)

Fig.16: On the top-right, simulator environment (Hale, n.d.)

Fig.17: In the centre, In-game HUD/status bar (Hale, n.d.)



Fig.18: Post-game/leaderboard interface, displayed on a different computer (SKILL DRILL, n.d.)



Iconography and illustrations
The icons and pictograms used throughout the system have also been personalised to help users understand technical metrics intuitively. These include ball spin direction, mode symbols, and statistical representations.

The analysis of Skill Drill makes it clear how important it is to design simulator interfaces that can be used by different types of users, from professional athletes and coaches to recreational players.
This diversity requires a clear hierarchy of information: the interface must be accessible and intuitive for beginners while enabling expert users to access more advanced settings and detailed data as required. The system achieves this balance through a layered design approach, where complexity is revealed gradually rather than all at once.

Another key insight lies in differentiating between interface contexts. The in-game UI is deliberately minimal, displaying only essential indicators and leaving the virtual environment visually unobstructed to support immersion and focus. In contrast, the setup interface on the external computer has a denser, data-rich layout where users can configure modes, review statistics and adjust technical parameters.

Finally, the home screen is a prime example of clarity and usability. It organises the list of exercises in a clean, schematic way that makes navigation immediate and easy to understand, thereby reinforcing the importance of structured simplicity in these kind of environments.

2.2.2 SkyTechSport: A dynamic ski and snowboard simulator

SkyTechSport designs indoor ski and snowboard simulators that are intended to recreate the sensations, physics and environment of real snow sports. The company's vision is to eliminate the seasonal, spatial and environmental constraints of snowsport training, allowing users to practise all year round at home or in commercial settings.
The system delivers real G-force, immersive virtual environments and precise motion tracking to produce an experience that closely mimics actual skiing dynamics.

SkyTechSport simulators are designed to suit a wide range of users, from enthusiasts, to professional athletes looking for high-performance training equipment.

They are particularly valuable for aspiring and competitive skiers or snowboarders who want to improve their technique, build muscle memory and enhance their carving precision, edge control and race performance, as well as for ski schools, indoor training studios, fitness centres and event organisers, who use them as instructional platforms

Fig.19: On the top, simulator components, phisical environment (Ski Simulators, n.d.)

Fig.20: In the centre, an athlete using the simulator (Ski Simulators, n.d.)

Fig.21: On the bottom, setup interfaces (Ski Simulators, n.d.)

and engaging attractions. As these user groups have different levels of motivation, skill and familiarity with technology, the design must strike a balance between simplicity and accessibility, and the depth and configurability required by expert users.

In terms of the interface and interaction, the system uses an immersive in-simulation interface comprising panoramic visual environments (e.g. mountain slopes and race courses), which are projected onto VR headsets or large screens in order to immerse the user (Ski Simulators, n.d.). This minimises non-essential UI overlays that could disrupt the sense of immersion, enabling users to focus on motion, terrain and visual feedback. Users can also select different slopes, adjust the snow conditions and choose between race and game modes on the separate interface displayed on the computer. This has already been implemented in the simulation setup, enabling external users to track the position of athletes and view their statistics in real time, as illustrated in Fig. 20 and 21.

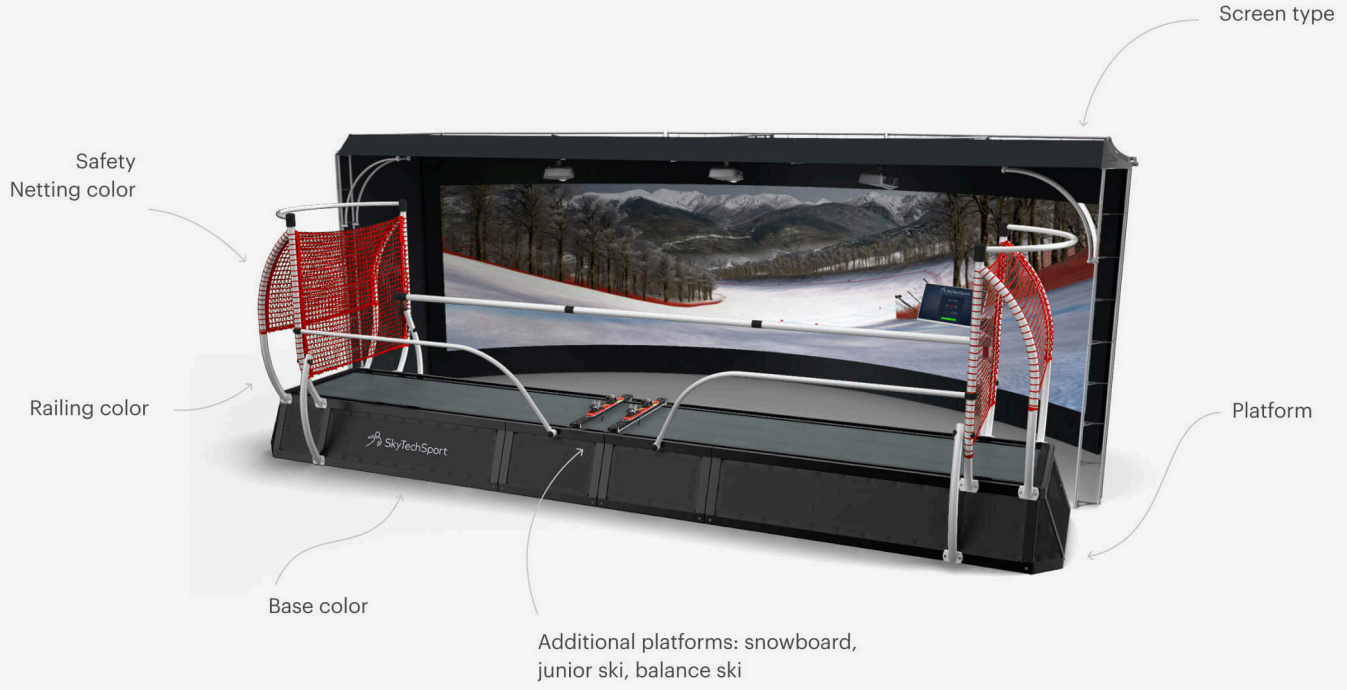
The system uses 'multiple sensors' to track motion, edge angles and position 'second by second'. This data are processed and converted into feedback via the simulation visuals and motion response.
The system also includes live leaderboards, enabling users to compete regionally or globally, as well as a mobile app to track session stats.

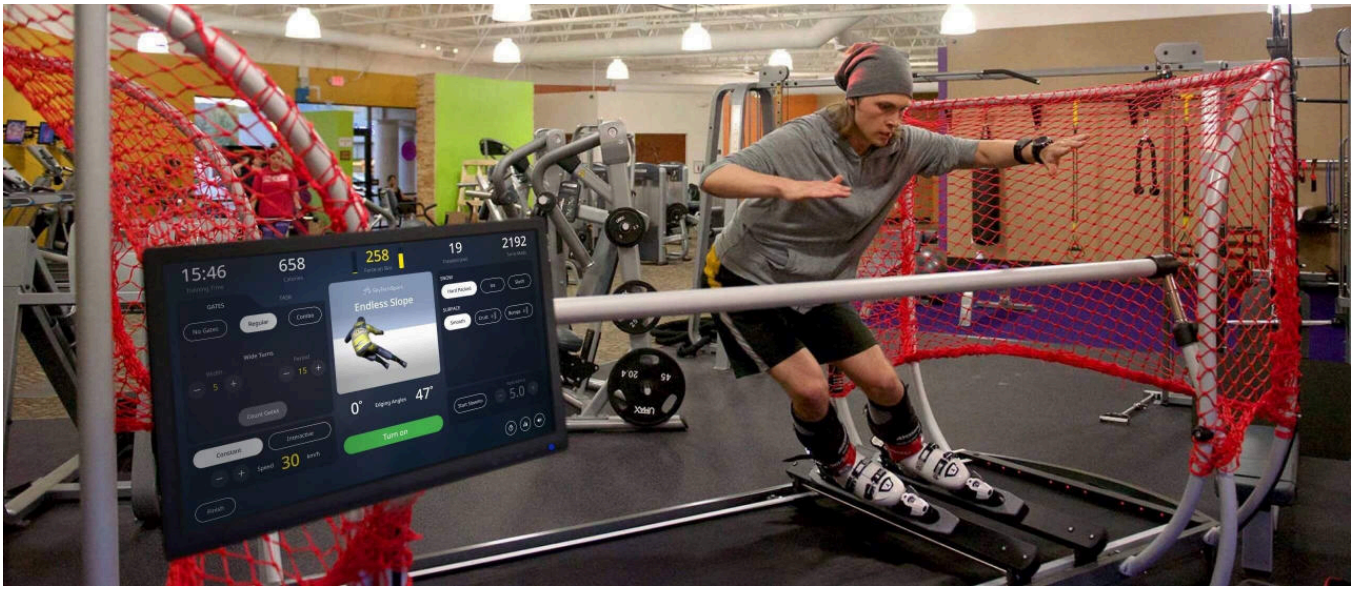
The key insight gathered from this case study is the adaptability of the system. It is highly configurable to meet the needs of different users and can be adjusted for various sports, such as snowboarding, or adapted for Paralympic training. In terms of spatial constraints, the system is flexible and offers models in multiple sizes to fit both compact indoor setups and professional facilities. It can also operate with either panoramic screens or a VR headset. It dynamically adapts to different virtual environments and renders a realistic sense of slope and descent, even on a horizontally fixed platform.

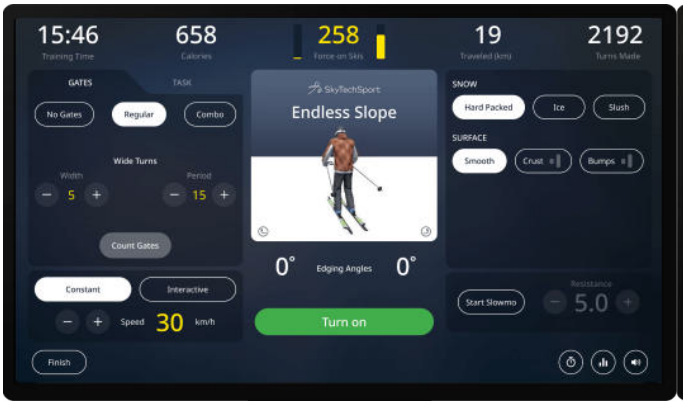
Finally, the differentiation between the simulation and management interfaces is crucial: the UI on the simulation screen is absent to preserve immersion, while the UI in the control screen contain detailed data and configuration options. The control interface also provides real-time performance metrics, enabling coaches and technicians to efficiently monitor and adjust training. This type of simulator is particularly relevant to this thesis, as it can be compared to the sliding simulator, since both involve high-speed motion and precise bodily coordination.

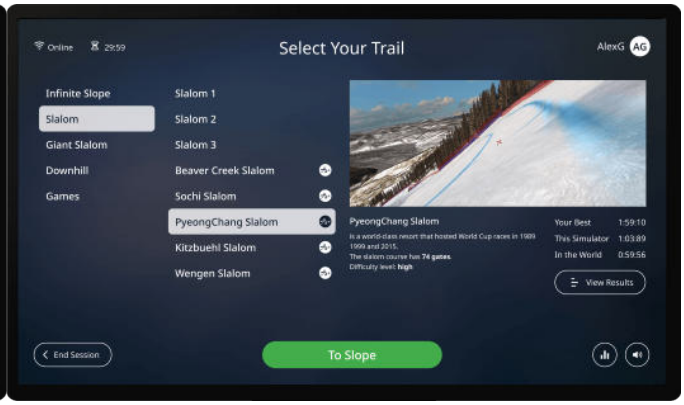
2.2.3 Black Box VR: A VR-Integrated resistance exercise machine

Black Box VR is a single, powerful exercise machine that delivers a full-body workout in a virtual reality environment.


Screen type
Safety
Netting color
Railing color
Platform
Base color
Additional platforms: snowboard,
junior ski, balance ski
SkyTechSport


15:46
658
258
19
2192
Endless Slope
47°
0°
30
Turn on


15:46
Training Time
658
Calories
258
Force on Skis
19
Traveled (km)
2192
Turns Made
GATES
TASK
No Gates
Regular
Combo
Wide Turns
Width
5
Period
15
Count Gates
Constant
Interactive
Speed
30
km/h
Finish
SkyTechSport
Endless Slope
0°
Edging Angles
0°
Turn on
SNOW
Hard Packed
Ice
Slush
SURFACE
Smooth
Crust
Bumps
Start Slowmo
Resistance
5.0


Online
29:59
Select Your Trail
AlexG
AG
Infinite Slope
Slalom
Giant Slalom
Downhill
Games
Slalom 1
Slalom 2
Slalom 3
Beaver Creek Slalom
Sochi Slalom
PyeongChang Slalom
Kitzbuehl Slalom
Wengen Slalom
PyeongChang Slalom
Your Best
1:59:10
This Simulator
1:03:89
In the World
0:59:56
View Results
End Session
To Slope

It adapts resistance in real time to maximise fitness results, something that traditional gyms and home equipment cannot do.
It blends strength training, HIIT cardio and a gamified VR experience into one immersive session.

The system uses an ElectroForce Drive resistance machine capable of delivering weight resistance which is automatically adjusted based on user performance, eliminating the need for manual weight changes. The handles and bench pad are also configured automatically to align with the user's body geometry, simplifying setup.

The simulator caters for a wide range of fitness levels, from beginners to elite athletes, thanks to its extensive resistance range and self-adjusting capabilities. As a VR eSports gym, users engage in 30-minute 'battles', combining exercise and gaming to either defend or destroy virtual objectives. The system also provides data and performance metrics via a companion app with some analytics interfaces, enabling users to track their progress over time (BlackBoxVRgym, 2025).

Within the VR environment, the user interacts by grabbing real handles, that are alligned with the virtual ones visible in the VR environment. Exercise motions are mapped to 'Exercise Attacks' in the virtual game: each repetition (e.g. chest press, squat or deadlift) launches a corresponding attack in the game world. The system continuously tracks each repetition and set, using this data to adjust the resistance and progression for the next session via machine learning/AI.

The Black Box VR system provides valuable insights into the meaningful integration of gamification into physical and athletic training, even at advanced or professional levels.
In this case, the user is positioned as both athlete and player and must engage in two activities simultaneously: performing real strength exercises with precision and consistency in order to outperform their virtual opponent. While not explicitly designed as a cognitive dual task, this dynamic introduces an additional layer of engagement and focus, thereby enhancing motivation and performance quality.

The interface is entirely situated within a VR environment, merging physical exertion with interactive gameplay. A companion app tracks progress, improvements and detailed performance statistics over time.
Of particular interest is the system's adaptive difficulty feature, which uses artificial intelligence algorithms to analyse user data and dynamically adjust resistance and intensity. This ensures optimal training conditions for each individual.

Fig.22: User using the simulator (BlackBoxVRgym, 2025)



Fig. 23: The game virtual environment (BlackBoxVRgym, 2025)



Fig. 24: Simulator basic setup (BlackBoxVRgym, 2025)



3.

TRAINING AND CONGITIVE TASKS

This chapter examined the training routines of bobsleigh athletes, and explored the theoretical basis of cognitive tasks in sports training. It then analysed cognitive and dual-task training methods in various sports, demonstrating how perception, anticipation and reaction times can be improved through specific exercises and interactive systems. Finally, the chapter presented three cognitive tasks that have been integrated into the sliding simulator. These tasks provide a structured framework for training repetition, visualization, and muscle memory in an immersive environment.

3.1 TRAINING OF BOBSLEIGH ATHLETES

An examination of the training routines of bobsleigh athletes reveals a clear pattern: this discipline require a delicate balance of physical power, technical precision, and cognitive control.

Bobsleigh athletes dedicate much of their training to develop explosive strength and sprinting speed. The initial push phase has a significant impact on the sled's final velocity, making it one of the most critical performance factors. Training therefore focuses heavily on strength conditioning, weightlifting, and acceleration drills, often drawing inspiration from track and field programmes (Wacker et al., 2006).
Pushers and brakemen work on lower-body power, sprint mechanics and coordination, while pilots combine these sessions with exercises focusing on motor control and balance to improve steering accuracy.

In this context, physical preparation alone is not enough. As each track can only be used for a limited number of descents per season, athletes must also undergo cognitive training to maintain their readiness.
Every morning before competition or practice, pilots perform a track walk to observe and memorise the curves and ice conditions, and identify any elements that could influence speed or steering.
This activity strengthens spatial memory and visual anticipation, enabling the pilot to mentally rehearse the descent before entering the sled. As one bobsleigh pilot noted: *"Reacting during a curve means you are already too late"* (Axe Racing) so the ability to anticipate rather than react is key to success and minimising time lost during the descent.

Some athletes integrate neuro-motor exercises into their warm-up routines to improve reaction speed and cognitive focus. These exercises are commonly used in sports that involve speed. They involve catching or dodging unpredictable objects, such as tennis balls, in order to stimulate fast decision-making and peripheral vision. Others adopt personalised strategies: one bobsleigh pilot remarked that for him *"solving a Rubik's cube activates the same brain areas as the descent itself"* (Axe Racing), highlighting the connection between problem solving, pattern recognition and visualisation. Within this framework, visualisation emerges as one of the most powerful cognitive techniques.
Pilots often engage in mental imagery sessions, closing their eyes and visualising the track curve by curve while synchronising their imagined steering movements with the rhythm of the descent.

Studies in cognitive sport psychology confirm that such practices

enhance motor learning and reaction efficiency by reinforcing the neural pathways involved in actual performance (Witte et al., 2025).

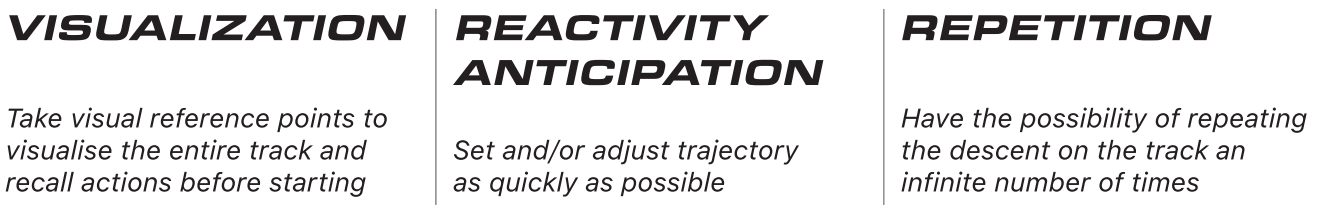
In conclusion, sliding sport professional athletes mostly rely on physical training, but to perform at their best, they should also develop cognitive abilities such as the capacity to visualise, memorise, anticipate, and react effectively under pressure.

Visualisation is the athlete's ability to simulate the descent in their mind before or during the run, taking into account visual reference points, kinaesthetic memory and motor imagery. This involves recalling the sequence of turns and timing cues in order to anticipate upcoming actions. In sliding sports, visualisation enhances spatial awareness and decision-making in high-speed conditions, enabling consistent performance even without real sensory feedback.

Reactivity and *anticipation* are key to an athlete's ability to perceive environmental cues and adjust their trajectory or steering input in response to dynamic changes. This task involves predictive processing, which involves recognising patterns and preparing actions before the full stimulus occurs. In sliding sports, where decisions must be made in the blink of an eye, high levels of anticipation enable athletes to maintain optimal trajectories and compensate for unexpected disturbances.

Finally, *repetition* is fundamental, and involves systematically performing the same motor and cognitive sequences multiple times in order to consolidate procedural memory and improve precision. In simulated training, repetition enables athletes to experience an unlimited number of controlled descents, thereby refining their perception–action coupling, reducing their reaction times and stabilising their technical execution, all without the physical and logistical constraints of a real track.

Fig 25: Diagram summarising the fundamental cognitive abilities that sliding sports athletes need to develop



3.2 COGNITIVE AND DUAL-TASK TRAINING

Cognitive tasks are structured exercises designed to stimulate and evaluate particular mental abilities, such as attention, working memory, decision-making, and visual processing. In sports science, cognitive tasks are used to train the cognitive mechanisms that underpin perception and action, thereby enhancing an athlete's ability to make rapid and accurate decisions in dynamic, high-pressure environments.

The effectiveness of such exercises can be explained by Cognitive Load Theory (CLT), a well-established framework originating from problem-solving studies in educational psychology. CLT assumes that working memory has a limited capacity and that the cognitive load associated with a task determines how much of that capacity is used.
Cognitive load can be divided into three components: Intrinsic, extraneous and germane load, each of which has specific implications for task design (Moreno, 2010).

- *Intrinsic load* refers to the difficulty of the task itself and depends on the prior knowledge of the learner (Sweller, 1994);

- *Extraneous load* refers to the way an instructional task is presented (Sweller et al., 1990);

- *Germane load* consists of the cognitive resources devoted to schema acquisition and automization (the development of specific cognitive representations to automatically process information) (Sweller et al., 1998).

These three sources are additive, and for elite athletes, balancing these loads is essential: training tasks should be designed to increase germane load while minimising extraneous distractions.

In this context, dual-task training becomes an especially effective method for professional athletes. According to Huang and Mercer (2001), dual-task procedures involve carrying out two activities at the same time to evaluate attentional requirements and the effect of additional tasks on performance.
The primary task corresponds to the main motor or perceptual action, such as steering the sled, while the secondary task introduces an additional cognitive or sensory load, such as responding to a sound or visual cue. Research shows that the more demanding the primary task is, the more attentional resources are required to maintain an acceptable level of performance (Abernethy, 1988; Schmidt, 1988).

From the perspective of Cognitive Load Theory, dual-task training deliberately introduces an additional cognitive load to simulate the stress experienced during real competition. Bobsleigh pilots, for example, must process vast amounts of multisensory information, such as visual cues, vibrations, balance shifts and auditory feedback, while making precise steering decisions at speeds exceeding 130 km/h. In such extreme conditions, attention must be divided and prioritised efficiently.
Training under dual-task conditions helps pilots automate technical gestures, filter relevant information, and maintain high performance even when cognitive resources are limited.

Furthermore, the expertise reversal effect (Kalyuga et al. 2003) explains why experienced pilots benefit most from this method.
Skilled performers can integrate additional task-relevant information using existing schemata without increasing cognitive load; however, novices may experience overload due to their limited prior knowledge.
Thus, for expert bobsleigh pilots, increasing task complexity through dual-task exercises enhances learning efficiency rather than hindering it, fostering better anticipation, reaction and situational awareness.

To gain a better understanding of how cognitive skills are practically used in sports training, an extensive investigation was conducted into the dual-task methods and tools employed in various disciplines.
The study examined how athletes combine physical and cognitive demands during training and identified approaches that could be adapted for bobsleigh and other sliding sports.

3.2.1 Auditory dual-task training in Rugby

Gabbett, Wake and Abernethy (2010) investigated the use of dual-task training to understand how cognitive load influences technical execution in rugby league. Athletes were asked to perform a key tactical action, while completing a secondary auditory task. The added auditory stimulus increased attentional demand, enabling researchers to measure the degree to which the primary gesture had become automatic.

This approach showed that combining different sensory modalities (a visual–motor primary task and an auditory secondary task) can effectively train divided attention without causing interference.
It also reinforced athletes' ability to maintain technical precision while processing non-visual stimuli, a crucial skill in chaotic match situations.

3.2.2 Witty-SEM cognitive–motor training system

The Witty-SEM, is an intelligent training system designed to improve athletes' cognitive and motor performance by using interactive visual stimuli. The device consists of a 7×5 LED matrix capable of displaying symbols, colours and dynamic light patterns (Microgate, n.d.).



Fig.26: On the top, example of the application of the Witty-SEM (Microgate, n.d.)



Fig.27: On the left, Interaction required to turn off the light (Microgate, n.d.)



Fig.28: On the right, system components (Microgate, n.d.)

Each module contains a proximity sensor that detects user interaction, enabling real-time feedback and adaptability for different exercises.

The Witty-SEM system was originally developed for sports such as basketball and football. It enables coaches to combine physical exercises with cognitive challenges, thereby transforming traditional training sessions into dual-task exercises. Athletes must respond to visual cues while continuing to perform the technical or tactical task.
These tasks target anticipation, selective attention, decision-making and working memory, thereby simulating the perceptual–cognitive load experienced in competitive environments (Microgate, n.d.).

The system's flexibility is one of its most notable strengths.

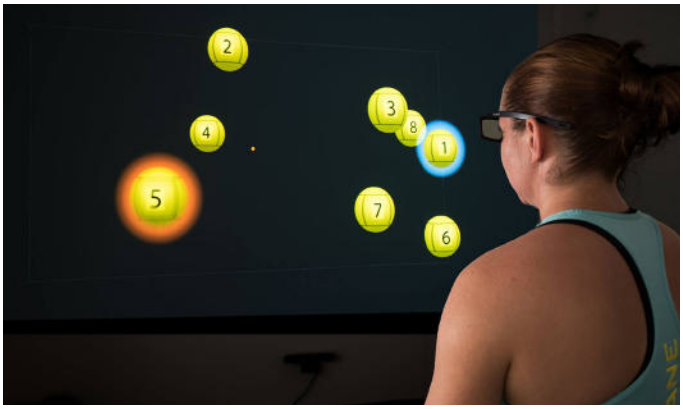
Each session can be customised in terms of timing, difficulty and type of stimulus, enabling Witty-SEM to be adapted to individual skill levels and sport-specific objectives. Exercises can focus on improving reaction time, coordination or perceptual–motor integration, and can be configured to encourage either teamwork or individual responsiveness. The system can also integrate multiple devices placed across the training area to create complex, multi-stimulus environments.

3.2.3 NeuroTracker, dual-task training

NeuroTracker is a perceptual–cognitive training system designed to enhance the brain's capacity to process multiple sources of information simultaneously. The platform uses 3D multiple-object tracking exercises in an immersive environment to train selective attention, working memory, coordination and decision-making under time pressure.

During a standard NeuroTracker session, the user sits in front of a 3D display and wears active-shutter glasses. Eight identical spheres move through three-dimensional space and, for a few seconds, a subset of these (usually four) are highlighted, these are the targets.
Once the highlight disappears, all of the spheres move randomly and at an increasing speed. The athlete must then mentally track the target spheres until they stop and identify them. In dual-task mode, this visual tracking exercise is combined with a secondary task, such as maintaining balance, performing physical drills or making tactical decisions.
For instance, an athlete might perform coordination movements or verbally respond to strategic cues while simultaneously tracking the targets. This setup challenges the perceptual–cognitive and motor systems simultaneously, training the brain to remain accurate and focused despite competing demands (NeuroTracker, n.d.).

Research and applications demonstrate that NeuroTracker training improves mental speed, attention span and situational awareness. Athletes who use the system demonstrate quicker anticipation,



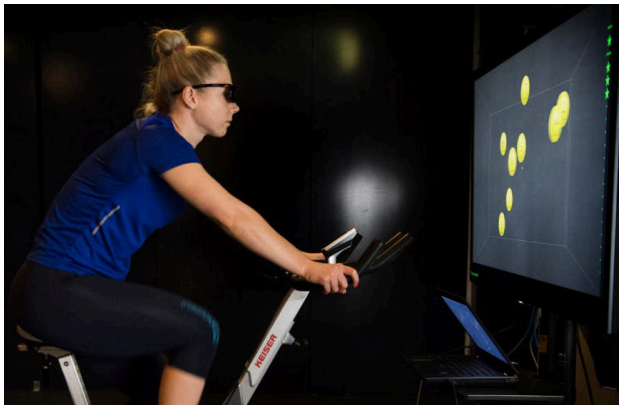


Fig.29: On the left, NeuroTracker basic training (NeuroTracker, n.d.)

Fig.30: On the right, NeuroTracker dual-task training (NeuroTracker, n.d.)

faster reaction times, and more consistent decision-making under stress. These effects have been observed in a variety of disciplines, including football, hockey, racing, and skiing, where rapid environmental processing is essential.

3.2.4 Summary and key insights

This section explored the role of cognitive training in improving the perceptual-motor performance of athletes in high-speed, high-stress disciplines such as bobsleigh. Drawing on Cognitive Load Theory, the section emphasised the importance of balancing intrinsic, extraneous and germane cognitive loads in order to optimise task design.
In elite sports, achieving this balance enables athletes to automate complex motor actions while maintaining attentional flexibility and decision-making efficiency.

Dual-task training has emerged as an effective method of replicating the cognitive demands of real competition, involving the introduction of a secondary task that increases mental load. Studies have shown that such exercises can improve selective attention, anticipation and reaction time, particularly among expert athletes, who are able to process additional information without experiencing cognitive overload.

In practice, the most common implementations use visual stimuli in the form of sequences of numbers, shapes, or colours.
Athletes must identify, memorise or react to specific patterns while continuing to perform the primary motor task. Studies have shown that embedding dual-task exercises in a real or virtual sporting environment leads to significantly greater performance transfer and contextual learning, since motor dynamics closely mirror those of real competition.

Case studies of existing systems demonstrated practical implementations of these principles. The Witty-SEM platform illustrates how interactive visual and motor tasks can train anticipation and decision-making through multi-sensory feedback. Meanwhile, NeuroTracker provides a controlled environment for developing selective attention and visual tracking under time pressure. Both systems illustrate how combining perceptual and cognitive stimuli can improve athletes' situational awareness, automaticity and response accuracy.

Overall, the findings confirm that incorporating cognitive load modulation and dual-task training into virtual simulation environments can significantly enhance the ecological validity of training systems.
For bobsleigh pilots, this approach allows exercises to be designed that more closely reproduce the perceptual and attentional dynamics of real descents, thereby fostering deeper learning, resilience under stress and improved performance consistency.

3.3 SLIDING SIMULATOR COGNITIVE TASKS

Having analysed the benefits, constraints and needs of both bobsleigh athletes' training methods and cognitive and dual-task methodologies, the sliding simulator developed in this thesis aims to integrate dual-task training in a highly realistic environment that replicates the Olympic bobsleigh track in Cortina d'Ampezzo.

The tasks designed for the Sliding Simulator draw on the key mental skills that bobsleigh pilots need to master in order to perform at their best: *visualisation*, *reactivity*, *anticipation* and *repetition*.
These abilities are fundamental for navigating the track efficiently, making split-second decisions, and maintaining precise control in the extreme conditions of the descent. The Sliding Simulator, provides a controlled environment in which these skills can be systematically developed, evaluated, and enhanced.

It is important to emphasise that these cognitive tasks have been carefully designed to meet the needs of professional athletes.
This includes the difficulty level of each exercise and the flexibility of their setup configurations. As previously discussed, these athletes have already acquired highly automated motor skills, enabling them to engage in high-level secondary tasks that demand a significant proportion of their cognitive resources.

The simulator's cognitive exercises are integrated training scenarios that combine perception, memory, and motion control in a single interactive environment. Each task targets a specific cognitive objective while accurately reflecting the perceptual and temporal demands of an actual bobsleigh run.

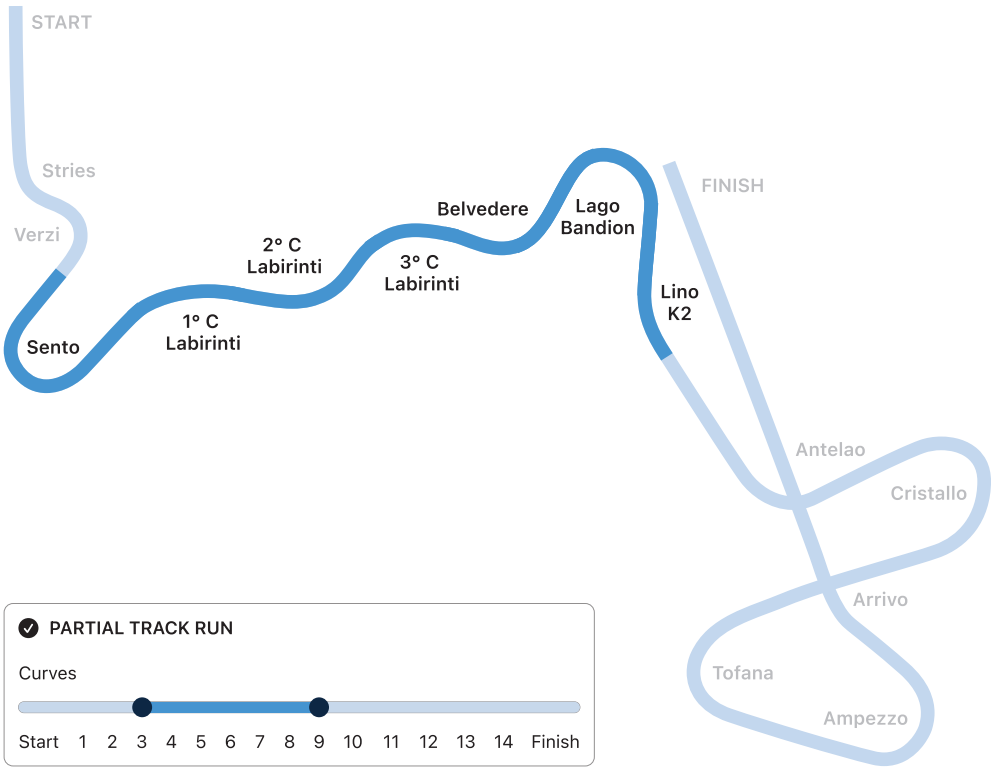
3.3.1 Full or partial track run: Repetition

This mode focuses on repetition and consolidation, offering pilots unlimited practice to refine their memory and coordination.
In line with one of the key benefits of simulation-based training, this exercise allows pilots to repeat full or partial runs without any of the spatial, temporal or environmental limitations of real-life scenarios.

In this configuration, the pilot can:

- Complete the entire virtual track, replicating a complete race descent to practise timing, coordination and trajectory optimisation;
- Select and train on specific sections of the track to isolate critical

Fig.31: Example of a Partial track run exercise



segments, such as complex curves or transition areas, for targeted practice and refinement.

By enabling an unlimited number of repetitions in consistent conditions, this mode facilitates the automation of skills and the development of muscle memory. It enables pilots to memorise the tracks and trajectories, allowing them to practise as much as they want.
It also enables precise feedback to be collected for performance analysis, helping athletes and coaches track progress over time.

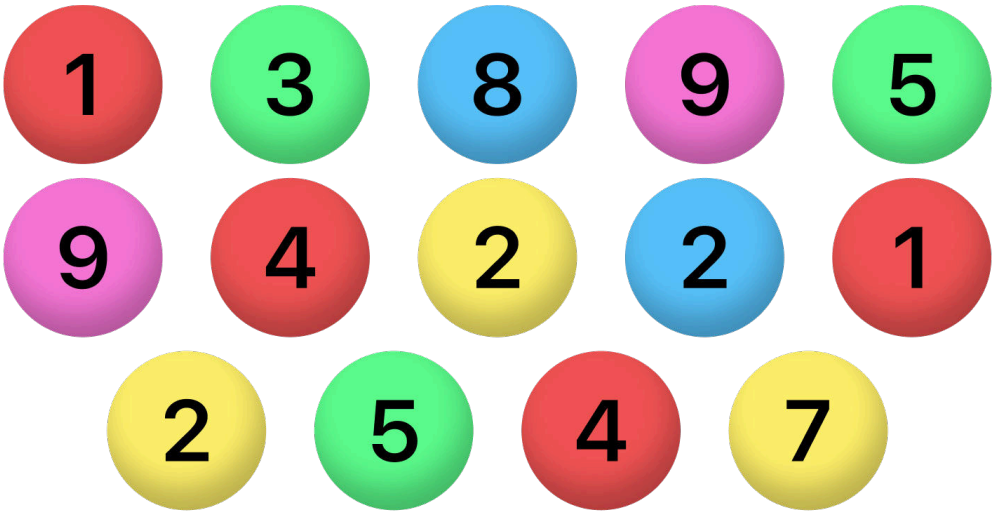
3.3.2 Bubble Memory: Visualisation and sequence recall

This dual-task exercise trains the athlete's ability to visualise the track. Visualisation is a key preparatory process for pilots, who rely on spatial memory and mental imagery to anticipate how the sled will behave along the course.

During the simulation, bubbles appear sequentially along the track as the pilot navigates the descent. Each bubble may display a colour, a number, or both. The coach predefines the total number of bubbles, with a maximum of 14 (one for each curve) and their characteristics according to the training objective.

The difficulty of the exercise increases based on the number and characteristics of the bubbles.

Fig.32: Example of Bubbles with colours and numbers



Bubbles appear randomly at one-per-curve points on the track, which are designed to replicate the main reference points that pilots usually take during the descent. The numbers range from 1 to 9, and the six colours (blue, green, yellow, red and pink) have been carefully chosen so that they can easily be distinguished during the descent.

In this configuration, the pilot should:

- Identify and process each bubble while maintaining control of the sled and an accurate trajectory;
- Memorise the sequence of colours and/or numbers, integrating visual scanning with cognitive focus;
- Recall and report the full sequence at the end of the run to reinforce working memory and perceptual–motor integration.

This exercise strengthens the connection between visual recognition, selective attention and memory recall, mirroring the need for pilots to internalise track sequences and visual reference points before each physical descent.

3.3.3 Blind curves: Reactivity and anticipation

This congitive exercise is designed to boost athletes' adaptability and control in unpredictable situations. It simulates the experience of temporary visual occlusion, forcing the pilot to rely on predictive cues and proprioceptive feedback rather than direct sight.

Anticipation, or the ability to act before a stimulus has fully appeared, is one of the most critical skills in high-speed sports, where reaction time

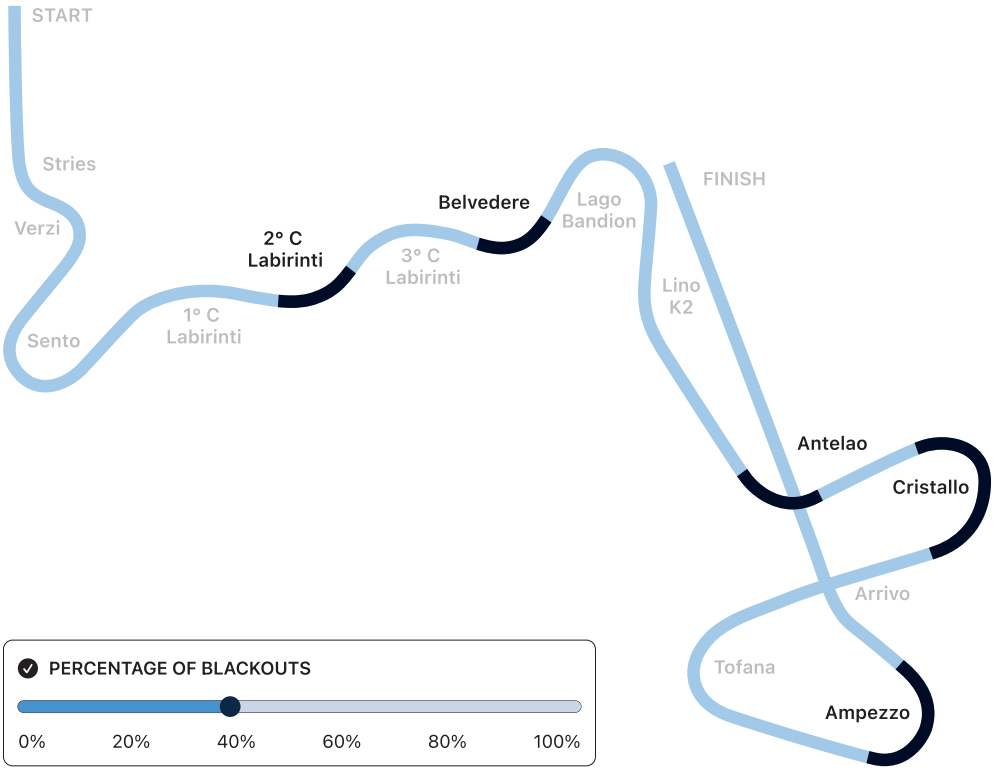
alone is insufficient. In order to train this skill, during the simulation the pilot encounters blind curves, which are sections of the track that are intentionally obscured from view.
The number of these curves can be decided by the coach, who can choose whether they appear randomly or manually. The size and position of the blind sections can easily be modified and they are designed to match the size and position of each curve.

In this configuration, the pilot should:

- Set the correct trajectory before entering the blind section using visual reference points and previously memorised spatial cues;
- Maintain control throughout the obscured area by relying on bodily sensations such as vibration and muscle memory;
- React and adjust the sled's path as quickly as possible when visual input returns, minimising trajectory error and preserving speed.

This task trains pilots to remain composed and precise in conditions of sensory deprivation. By forcing them to rely on internal cues, it enhances situational awareness and the ability to adjust steering based on kinaesthetic and vestibular information. As a result, pilots learn to maintain control and stability when environmental cues are limited or ambiguous.

Fig.33: Example of a Blind Curve exercise, where some sections of the track are obscured



4.

VIRTUAL ENVIRONMENT

This chapter outlines the design and development process of the virtual environment employed in the simulator. First, it outlines the creation of a preliminary model based on the Cesana track. This model is used to test materials, lighting, and regulatory elements derived from IBSF standards. It then goes on to detail the modelling of the final Cortina Sliding Centre environment. This includes remeshing, and creating all structural, environmental and lighting components in Blender and Unity. Finally, the chapter covers the integration of interactive elements for the simulator's training exercises.

4.1 CESANA: TESTS AND MATERIALS

The initial virtual environment was created using the Cesana track mesh, since the final mesh for the Cortina track had not yet been developed. This track was chosen because CONI had made its construction data available, making it a useful reference model.

As the long-term goal was to work with the Cortina track for the upcoming Olympic Games, the Cesana environment was used to reconstruct the structural and visual elements that would later appear in the Cortina Sliding Centre. As the track and surrounding infrastructure were still under construction, these elements were identified by analysing the executive project document *'CORTINA SLIDING CENTRE – Riqualificazione della pista 'Eugenio Monti' di Cortina d'Ampezzo, Lotto 2 – Infrastrutture Sportive'* in detail. This document specifies the architectural and structural components of the track, from safety barriers to support structures. Information about roofs, supports and the surrounding environment was inferred from the document's models and images, even when these were not explicitly described.

To ensure that the virtual reconstruction was as faithful to reality as possible, additional research was carried out on POV videos of modern and historical sliding tracks, as well as on the official IBSF track rules.

From this initial investigation, several design requirements emerged:

- *Track geometry*: curves, straights, inclinations and elevation changes must correspond accurately to the real track;
- *Ice surface*: the ice should feature realistic reflections, small imperfections and areas of varying shininess to convey texture and wear;
- *Walls and barriers*: heights and inclinations must match real dimensions and be made of believable materials, such as wood and reinforced structures;
- *Environmental context*: the surroundings should include grandstands, spectator areas, vegetation and parts of the mountain landscape that are visible from the pilot's viewpoint;
- *Aesthetic realism*: additional details, such as cables, technical equipment and personnel in operational areas, enhance immersion;
- *Lighting*: both natural and artificial lighting should realistically depict the alternating bright and shaded areas along the track.

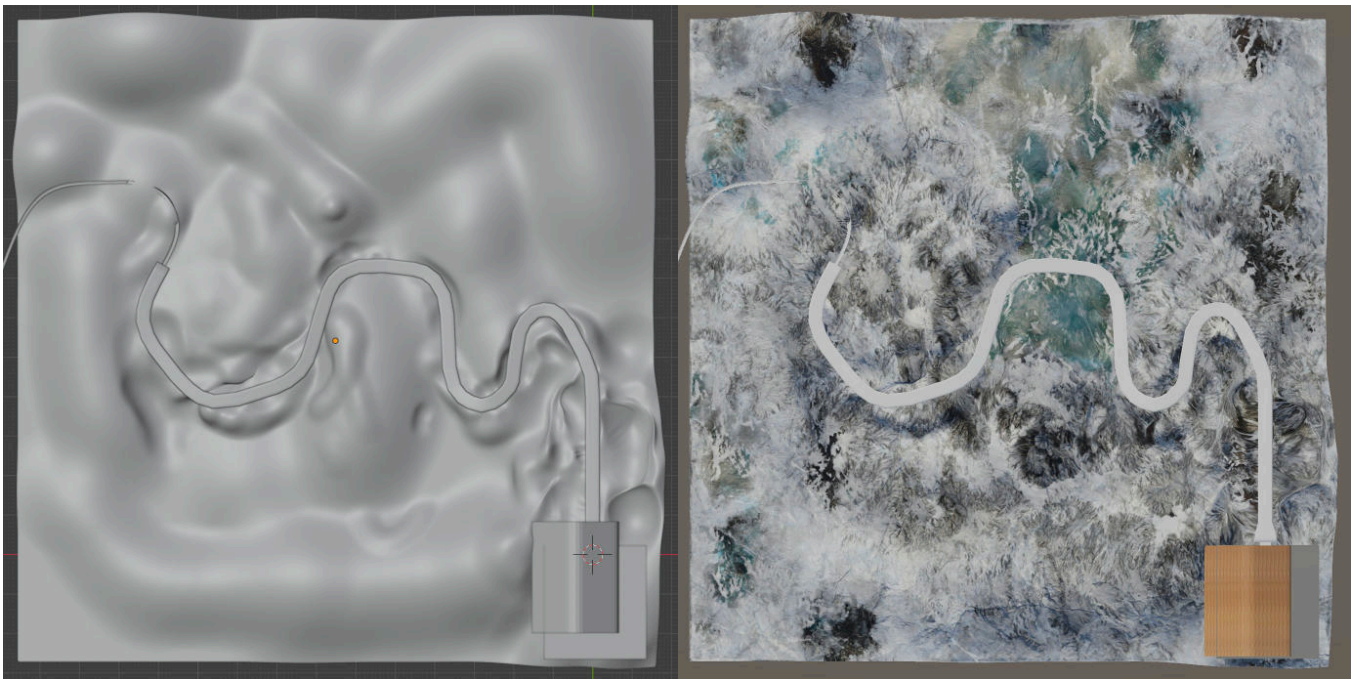
The second phase of the research project focused on the IBSF regulations, which stipulate that sections exposed to sunlight or adverse weather conditions must be protected by suitable structures.
Roofs are permitted only on bends; straight segments must use removable, single-sided covers. Permanent installations must be placed at least 50 cm from the inner wall and must not obstruct television filming or spectator visibility. The rules also define precise dimensional standards for the track's width, wall heights, transitions, start area and deceleration stretch, as well as for safety infrastructure and technical communication systems.

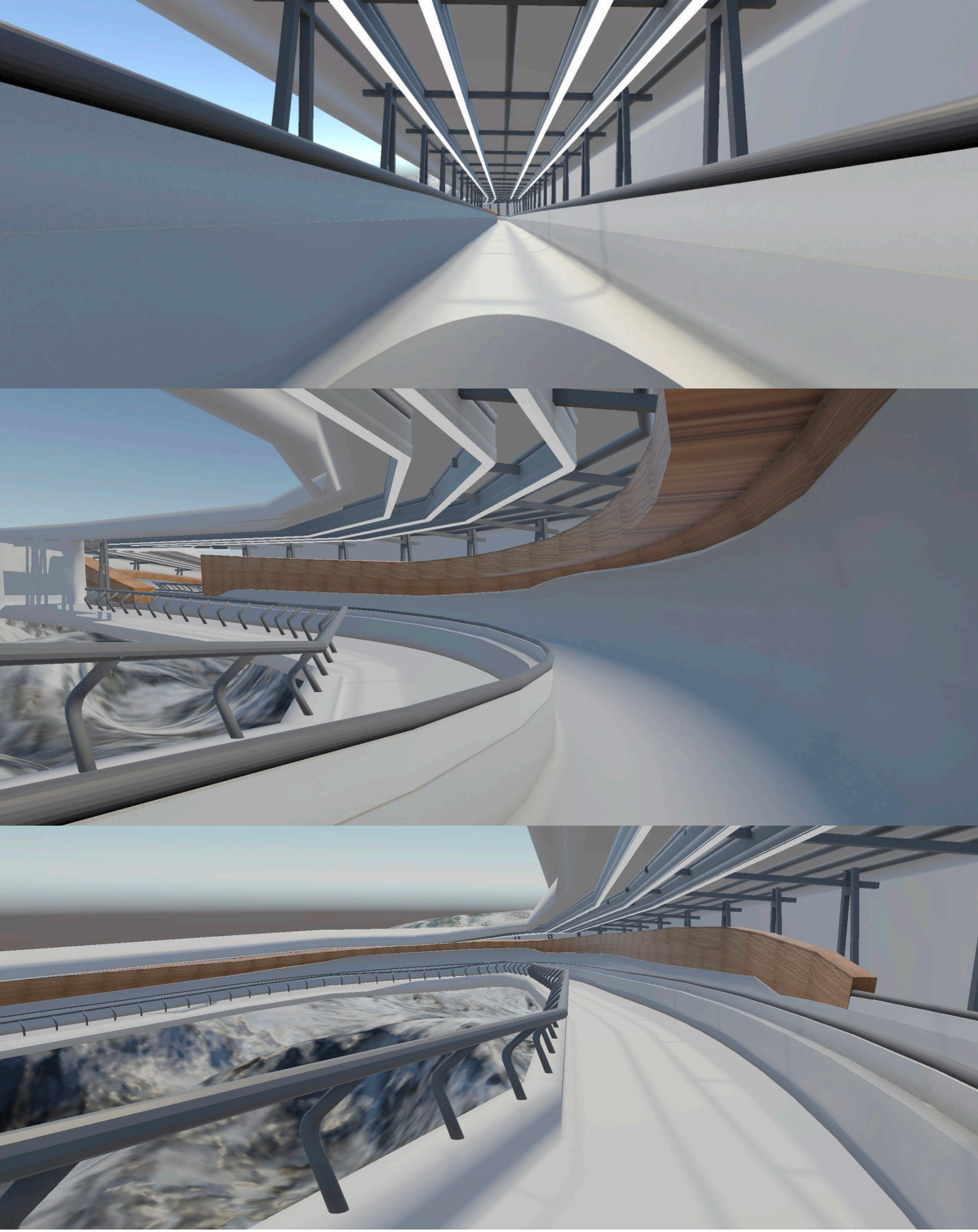
Based on these findings, the design process proceeded as follows.
First, the initial Cesana mesh, which only represented the ice surface in contact with the sled, was refined. Then, for the first section of the mesh, the main structural elements were modelled. Wooden protections for the curves and low perimeter walls were added, and the start was reshaped to comply with IBSF requirements.
After analysing the Cortina infrastructure plans, roof modules and their supports were designed for both curves and straights, with open gaps consistent with the official project documentation.
The first model of the start station was created, followed by the addition of lighting systems, walkway barriers, handrails and a winter mountain environment. Material management was performed in Unity to achieve optimal visual fidelity directly on the final platform. UV unwrapping was applied to all components requiring specific textures to ensure accurate material mapping and consistent rendering across the environment.

Fig.34: On the left, top-view of the virtual environment on Blender

Fig.35: On the right, top-view of the virtual environment on Unity

Fig.36: On the other page, specific views of the track with materials





4.2 CORTINA: THE FINAL VIRTUAL ENVIRONMENT

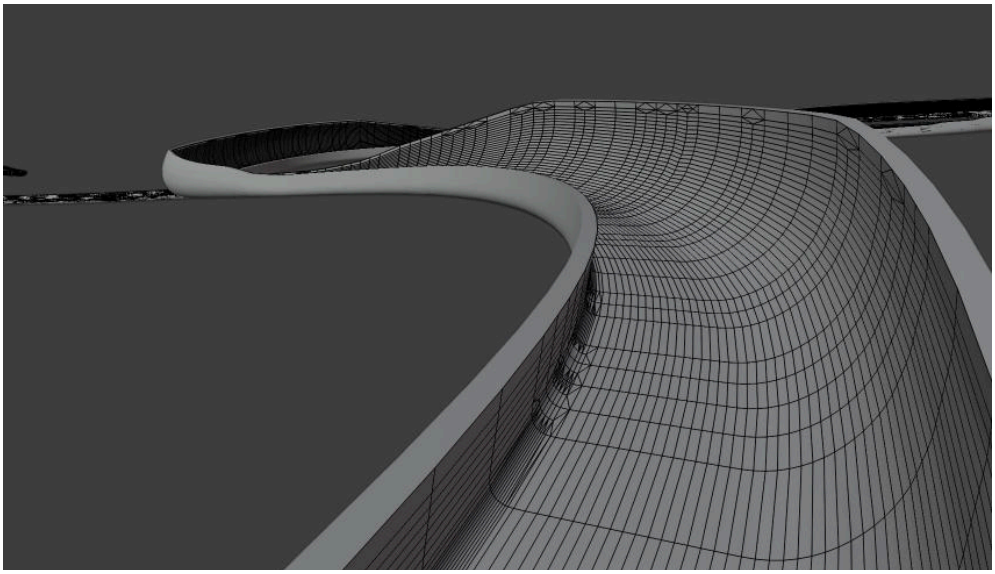
Having learned the basic structural and aesthetic elements through the first virtual environment, the next step was to create a definitive model of the track and its surroundings. Blender was used to model all the elements of the virtual environment.

The development process began with modelling the Olympic track at the Cortina Sliding Centre. The track's mesh was generated from a point cloud reconstructed using construction and topographic data found online, combined with aerial photographs of the site. The track is characterised by 14 curves, including three labyrinth sections, as well as five straight segments, including the start and finish lines.

The initial mesh was geometrically imperfect, particularly at the junctions between straight and curved sections, and along the upper walls of the curves. Several remeshing techniques were therefore applied to achieve coherent geometry suitable for simulation.

However, the initial result was still unsatisfactory as it was computationally intensive and caused issues during simulation, primarily due to the excessive number of vertices and the incorrect orientation of face and vertex normals. For this reason, the process was restarted from scratch. A new mesh was created and imported into Rhino, where it was remeshed to reduce the number of vertices while preserving geometric accuracy. This new mesh was found to be geometrically perfect and fully usable for simulation purposes (Fig. 37).

Fig.37: Final geometry of the track



In preparation for its integration into the virtual environment, the walls of the initial and final sections of the track were removed and replaced with low artificial walls, in line with the design of Olympic tracks.
The starting section was also widened. This is because in real tracks they are typically broader than the rest of the course.

Once the final track mesh was complete, the next phase was to model the surrounding virtual environment. Most of the elements were modelled by extruding curves derived from the duplicated perimeter of the track or other reference outlines of the surrounding structures.
As with the previous Cesana prototype, the first components modelled were the protective walls around the curves and the rigid barriers along the outer perimeter. These walls were built directly on the track's perimeter to ensure perfect alignment with its curvature and compliance with IBSF regulatory criteria.

After the barriers, the track walls themselves were constructed by extruding a cube along the direction of the track. Then, openings and gaps specified in the architectural plans were carved out.
All structural and accessory elements were designed based on the geometry and positioning of these walls: roof beams and support frames; tents and shading structures to block direct sunlight over the curves and straights; supports for roofs and barriers; handrails and safety barriers along the service walkway and the lighting system, which follows the track layout. The lighting design realistically differentiates between straight and curved sections: straight segments have four lamps, while curves have three, all of which are oriented towards the ice surface.

Next, the start and finish stations were modelled. Both stations were designed in line with the overall aesthetic and proportions set out in the Cortina Sliding Centre architectural project (Fig.42 & Fig.43).

The final step in the modelling phase was to create a realistic, contextually coherent mountain environment surrounding the track.
The track was situated within a believable mountain landscape by placing it in a non-snowy alpine forest setting.
The mountainous terrain was first generated in Blender using metaballs, and then refined to create natural slopes and elevation changes.
A large number of trees were distributed across the terrain using Blender's particle system to ensure a realistic density, as well as variation in scale and position. A mountain skybox was later added in Unity to make the surrounding environment look even more realistic.

Although the Cortina Sliding Centre is still under construction, the virtual environment was designed to accurately represent the expected real-world configuration of the site, based on available visual references.

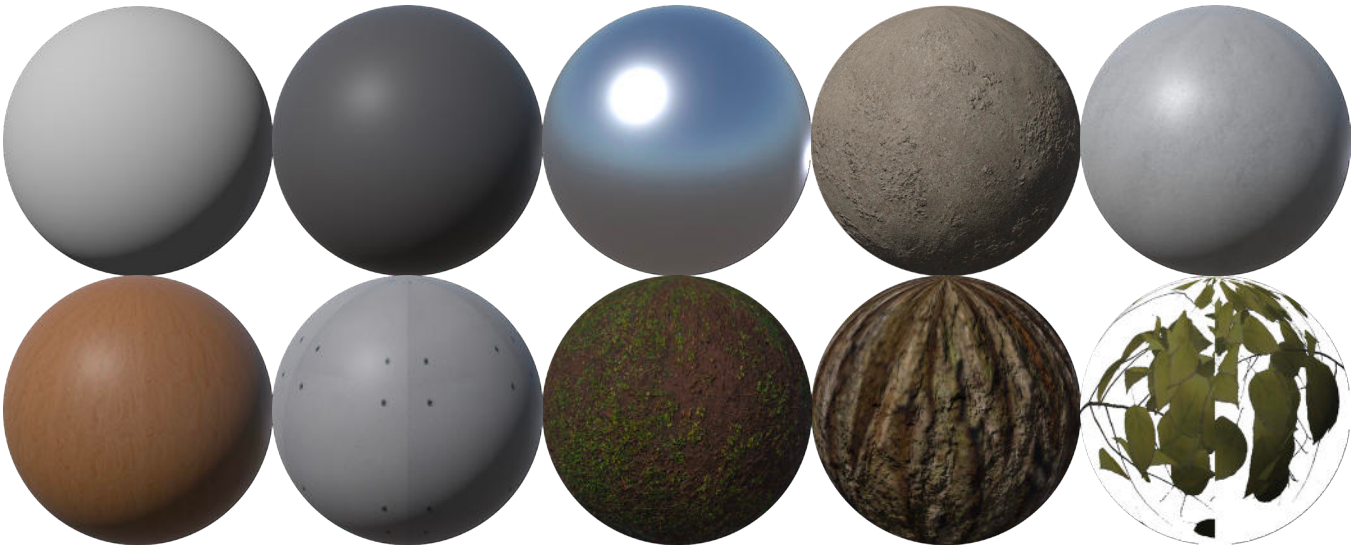


Fig.38: Materials used in the final virtual environment. From the top left: white for walls, gray for structural elements, metal, rock, snow, wood, plastic, terrain, bark, leaves

Once the entire virtual environment had been modelled, materials and lighting were added. To ensure compatibility with the simulation system, the Blender file was imported into Unity, where all material and light management was performed. This workflow prevented texture errors and guaranteed that all materials would render correctly within Unity's real-time engine.

Firstly, basic materials were created: the wall and roof colours; the colour of the bobsleigh; a metallic material for the structural elements, a semi-transparent shading one for the tents and a transparent blue glass for the arrival station windows. More complex materials were then introduced, including textured and lighting-reactive materials. Two rock textures were used for the start and finish stations; a wooden texture, was created for the station roof and curve support elements; a custom-made texture for the concrete walls; and materials for the trees and terrain, including bark, leaves and ground vegetation (Fig. 38).

Lighting management followed. To create atmospheric consistency, a skybox representing a non-snowy winter mountain environment was added. The default directional light in Unity was then rotated 90° on the X-axis to produce realistic shadows across all modelled elements.

To further enhance realism, a global volume featuring bloom and tone mapping effects was added. These effects increased the scene's depth and enabled light sources, such as the lamp bulbs along the track, to emit a visible glow thanks to their emissive materials.

Once the materials and lighting setup was complete, functional elements for the training exercises were added to the virtual environment to support the simulator's interactive components.

Fig.39: Top-view of the Cortina Sliding Centre. Planimetria della modifica alle opere di sostegno (Levorato, 2023)

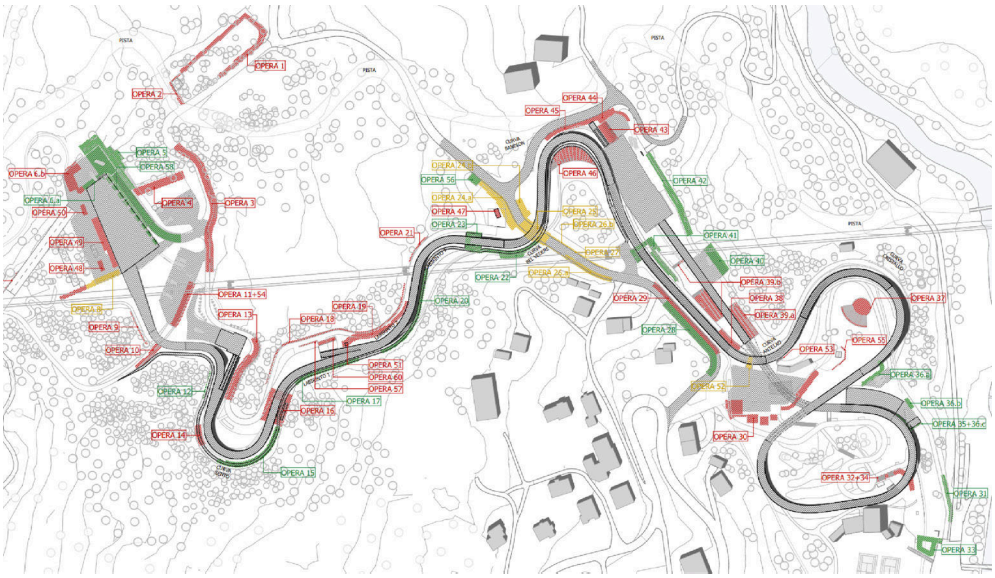


Fig.40: Top-view of the virtual environment on Blender

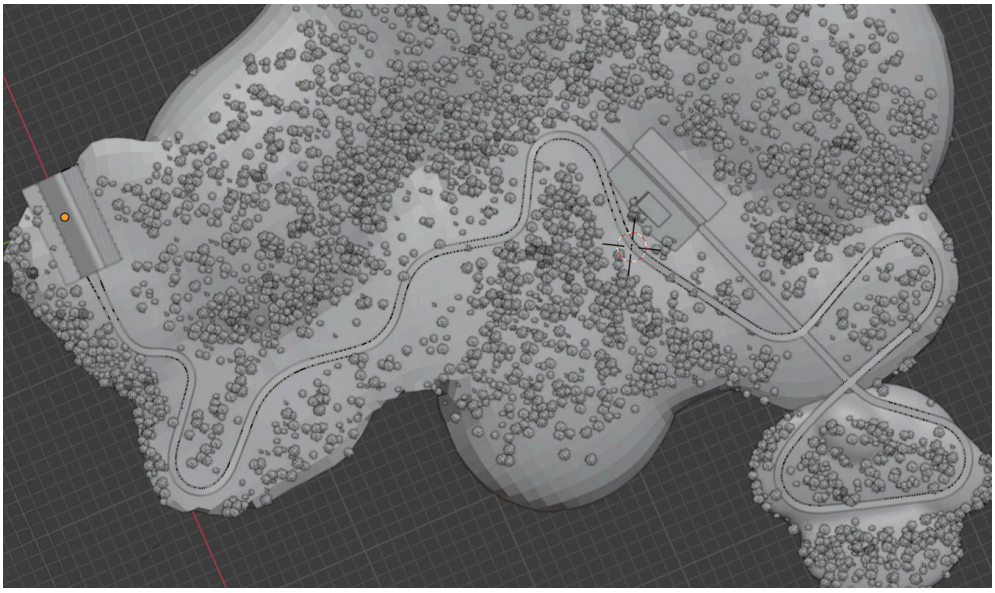
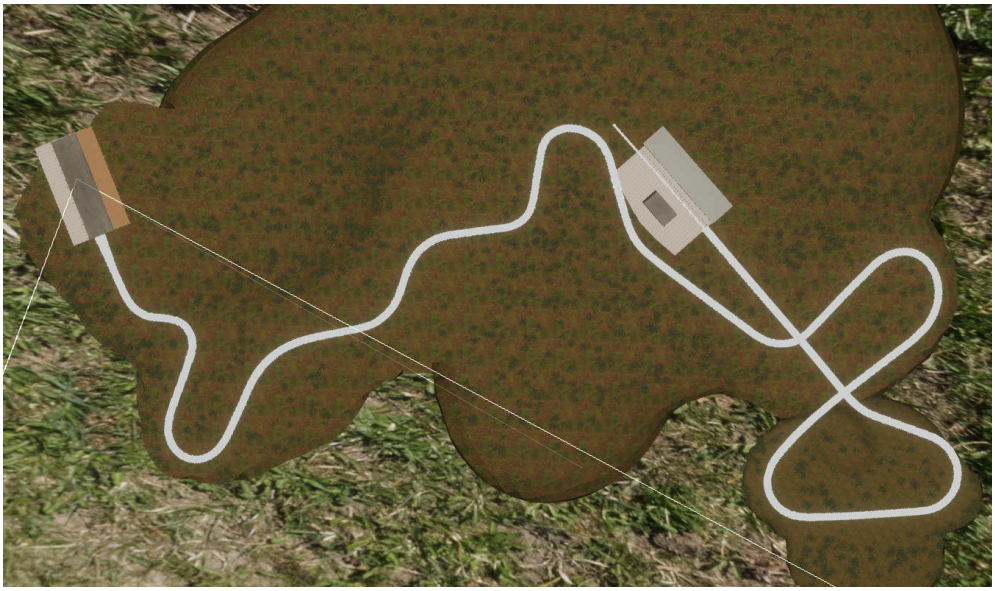


Fig.41: Top-view of the virtual environment on Unity



For the Track Run and Partial Track Run exercises, box colliders were placed along the track to define the start and finish points, as well as the spawn points for each of the 14 curves.

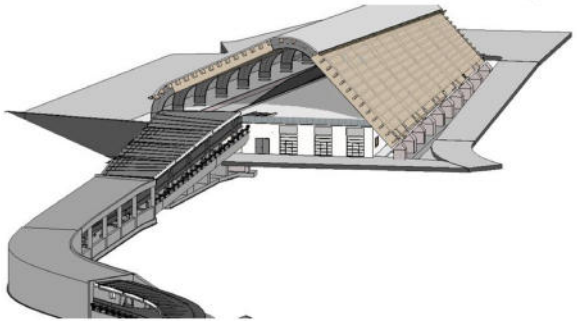
For the Bubble Memory exercise, 14 specific spawn points were selected, each located at the start of a wooden curve structure.
These positions were defined as box colliders within which a bubble prefab could appear; the visual and behavioural properties of this prefab are controlled via script.

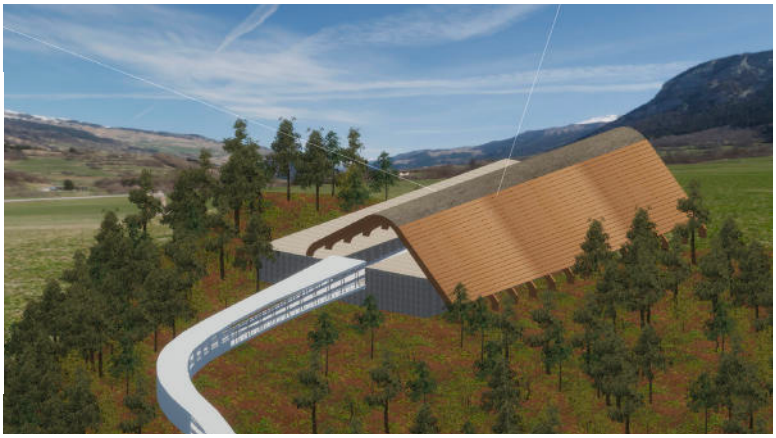
Finally, for the Blind Curves exercise, a series of box colliders of various dimensions were positioned to cover different portions of the track corresponding to each blind curve. These colliders define the start and end of the visually obstructed sections. As soon as the bobsleigh enters one of these colliders, a black panel is activated to obscure the pilot's view and remains active until the sled exits the collider. This system also allows the difficulty of the exercise to be easily adjusted: it is easy to move or resize the colliders to extend or shorten the blind zones, thus adapting the challenge dynamically.

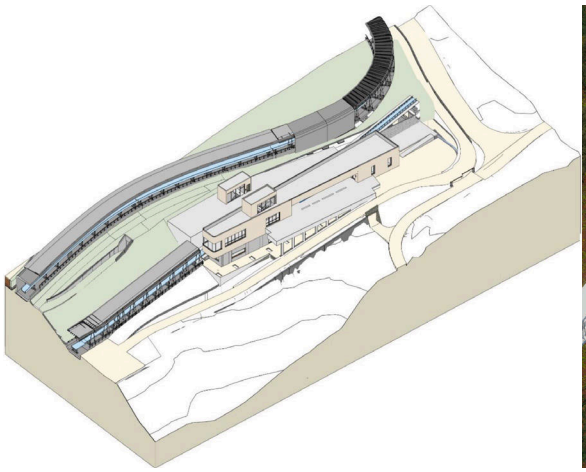
Fig.42: On the top, comparison between the starting building of the executive project and that of the virtual environment

Fig.43: On the bottom, comparison between the finish building of the executive project and that of the virtual environment

Fig. 44: On the other page, Bobsled POV of the track with materials



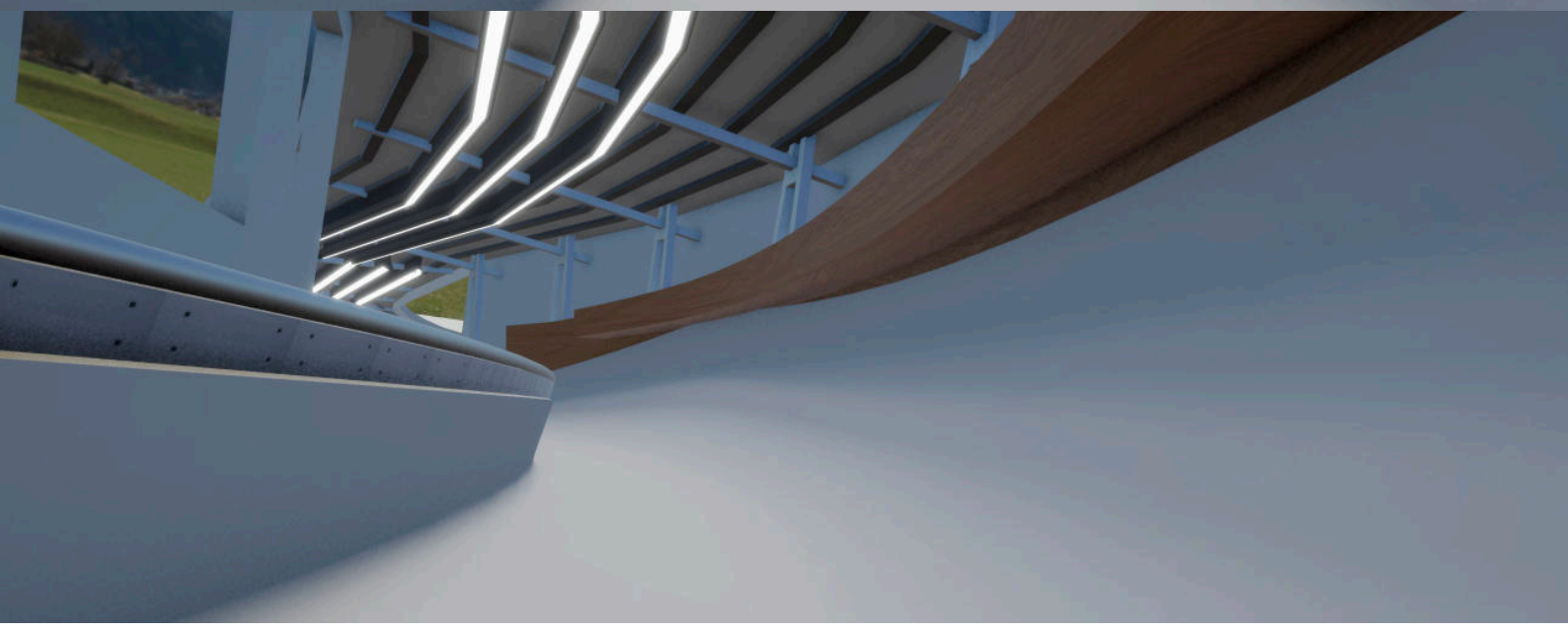












5.

INTERFACE AND INTERACTION DEVELOPMENT

The chapter defines the simulator's UX from foundations to final screens. It introduces three personas that inform the requirements for a dual-interface setup: an immersive pilot point of view (POV) and a secondary control user interface (UI) for coaches/operators.
The information architecture organises the experience into four phases: Access and Onboarding, Training Experience, Performance Review and Statistics. These are supported by wireframes and a cohesive design system. The interface as a whole emphasises clarity, consistency and scalability, adapting to both novices and professionals while enabling data-driven coaching and long-term performance analysis.

5.1 USER PERSONAS

As discussed in previous chapters, the simulator needs to be designed to accommodate different types of users, each with their own distinct goals, needs and expectations. These differences influence how they interact with the system and the kind of visual and informational feedback they require. To better understand and address these diverse needs, three main user personas have been identified:

- *The bobsleigh athlete*, is the one who should use the motion platform and the simulator for training.
- *The coach* prepares his athletes, designing physical and cognitive training routines and adjusting their difficulty.
- *The technical operator*, ensures that each training session is configured and calibrated to provide optimal conditions for every athlete.

The three users are now described in order to understand their goals, motivations, needs and frustrations.

5.1.1 Alex, the bobsleigh athlete



Age: 27
Role: Bobsleigh Pilot, National Team
Location: Cortina d'Ampezzo, Italy
Education: Sports Science graduate
Experience: 10+ years in competitive bobsleigh
Tech familiarity: High, uses fitness trackers, video analysis tools, and VR occasionally

Alex is 27 years old and competes internationally as a bobsleigh pilot for the italian national team. Having trained and raced for several years, he has developed solid technical skills, as well as a strong sense of focus and discipline. Passionate about continuous improvement, Alex pays close attention to every detail that could enhance his performance on the track. He is tech-savvy and keen to explore how it could complement his physical and cognitive training. He is competitive and curious, and is both goal-oriented and open to experimentation and innovation.

Goals and motivations
Alex's main objective is to familiarise himself with the track on which he will be racing and identify the most efficient racing line as quickly as possible. He aims to enhance his mental map of curves and transitions to boost his reaction time and precision in real runs.
He sees the simulator as a tool that enables him to train whenever he wants, repeat descents and analyse his performance, free from external constraints such as weather or track availability. His motivation ultimately lies in achieving consistency and mastery through deliberate practice.

Needs and expectations
- The ability to repeat and compare runs to refine his strategy and improve trajectory memory;

- A realistic and immersive simulation that reproduces the sensations, speed, and rhythm of real descents;
- Clear and immediate feedback about his performance, including metrics and visual cues;
- A simple, intuitive interface that lets him focus entirely on driving rather than system management.

Frustrations

- His training is limited due to weather conditions, access to the track and logistical issues;
- He suffers from a lack of immediate feedback during traditional training sessions;
- He has difficulty learning to recognise the best trajectories on straight and curved sections;
- He finds it difficult to be consistent in cognitive training, even though he knows it is an important part of the overall training.

5.1.2 Umberto, the bobsleigh coach



Age: 42
Role: Head Coach, National Team
Location: Trento, Italy
Education: Winter sports training and coaching degree
Experience: 10+ years as a professional coach
Tech familiarity: Moderate, uses digital tools for planning and data review but prefers simplicity

Umberto is an experienced bobsleigh coach who has worked with national-level athletes for many years. He has a deep understanding of the technical and physical demands of the sport and takes his responsibility towards his team very seriously.
Although he is not particularly tech-savvy, he utilises digital tools when they offer clear benefits for training and performance monitoring.
Curious and proactive, Umberto is always looking for new methods to improve his athletes' physical and mental performance.
Recently, he has become particularly interested in dual-task training, exploring how cognitive challenges can improve concentration and decision-making during descents. He is pragmatic and supportive.

Goals and motivations

Umberto's primary objective is to deliver the most effective and comprehensive training experience possible to his athletes. He aims to track each athlete's progress over time, identify their strengths and weaknesses, and design personalised routines combining physical performance and cognitive development. He is motivated by the prospect of using technology to make training more scientific, measurable and adaptive while ensuring it remains easy to manage and accessible to all.

Needs and expectations

- A centralized system where he can save and review each athlete's performance and progress;
- Simple and clear visual feedback that helps him quickly understand the outcomes of training sessions;
- Tools to design and adjust routines based on performance data and cognitive metrics;

- Easy-to-use interfaces that do not require advanced technical knowledge or setup.

Frustrations
- He finds it difficult to keep track of data from multiple athletes;
- He dislikes complex digital or technical tools that require excessive setup or specific expertise;
- He finds that there is limited access to customisable, integrated dual-task training programmes for each athlete.

5.1.3 Giacomo, the technician



Age: 29
Role: Simulation Engineer / Lab Technician
Location: Milan, Italy
Education: Master's Degree in Mechanical Engineering
Experience: 5+ years working with sports simulators and interactive training systems
Tech familiarity: Very high, expert in simulation hardware and software integration

Giacomo is an engineer who specialises in simulation technologies and motion systems. He has some years' experience working with training simulators and was part of the development team that built the current bobsleigh simulator. His in-depth technical expertise enables him to understand and manipulate every component, from motion algorithms to sensory feedback calibration. He is passionate about physics, robotics and human–machine interaction. For him, every small improvement, a smoother motion curve, a more responsive platform or more accurate data output, is a personal victory. Although he is highly technical, he is also collaborative and takes pride in seeing athletes and coaches benefit from his work.

Goals and motivations
Giacomo's main goal is to ensure that the simulator operates with the greatest possible precision and reliability. He is motivated by the challenge of continuously improving its accuracy, testing new configurations and refining technical parameters, in order to create a training experience that feels as close to reality as possible. Beyond engineering, he is driven by seeing his work translate into real-world results: athletes performing better, coaches gaining new insights and systems running flawlessly thanks to his attention to detail.

Needs and expectations
- Access to advanced system settings and diagnostic data;
- Development of a highly realistic environment that feels as close to reality as possible, in which he will attach physical behaviours;
- Monitor hardware and software performance in real time;
- Comprehensive analytics for debugging, maintenance and improvement.

Frustrations
- He finds it difficult to build a usable interface that can be understood by less experienced users;
- There is a lack of time or resources to test new experimental features or improvements.

5.1.4 Summary and key insights

These three user profiles were analysed to define the key characteristics of the interface.

Firstly, taking into consideration all the points that have been discussed thus far, the interface visible to the pilot should correspond exclusively to their point of view inside the bobsleigh. This view should be customisable according to each athlete's physical characteristics, such as height, to ensure a realistic and personalised experience.
The POV will be projected onto the curved screen integrated into the simulator setup, replicating the perception of an actual descent.

These user profiles make it clear that the main interface should be located on a secondary computer accessible to the coach and lab technician, but not the pilot. As outlined in the profiles, the interface must be intuitive and straightforward for the coach, and the purpose and functionality of the entire system must be clear to all users. The diversity of users requires a clear information hierarchy: while the interface must remain accessible to non-technical users, it should also allow experts to access more advanced settings and data when necessary.
To strike this balance, the system should adopt a layered design approach, revealing complexity progressively rather than all at once.

5.2 INFORMATION ARCHITECTURE

The information architecture was developed to organise the simulator's content and functionalities in a clear, consistent and user-centred way. It defines how users, can access, navigate, and interact with the system according to their different goals and levels of expertise.
The architecture maps the interface's logical structure, showing how exercises, settings, and statistical data are grouped and related.
Each section is designed to ensure intuitive navigation and quick access to essential features while maintaining a clean visual hierarchy.

The first diagram shows the main navigation options on the homepage and outlines the pathways to the different types of exercise, settings, simulation and profile management (Fig.45).

The login and registration section, which appears after selecting a discipline, is designed to be as simple as possible, requiring only a nickname. As the software is intended for internal use only, there is no need for a password or personal account system. Profiling is solely used to adjust the pilot's point of view within the simulator based on their physical characteristics.

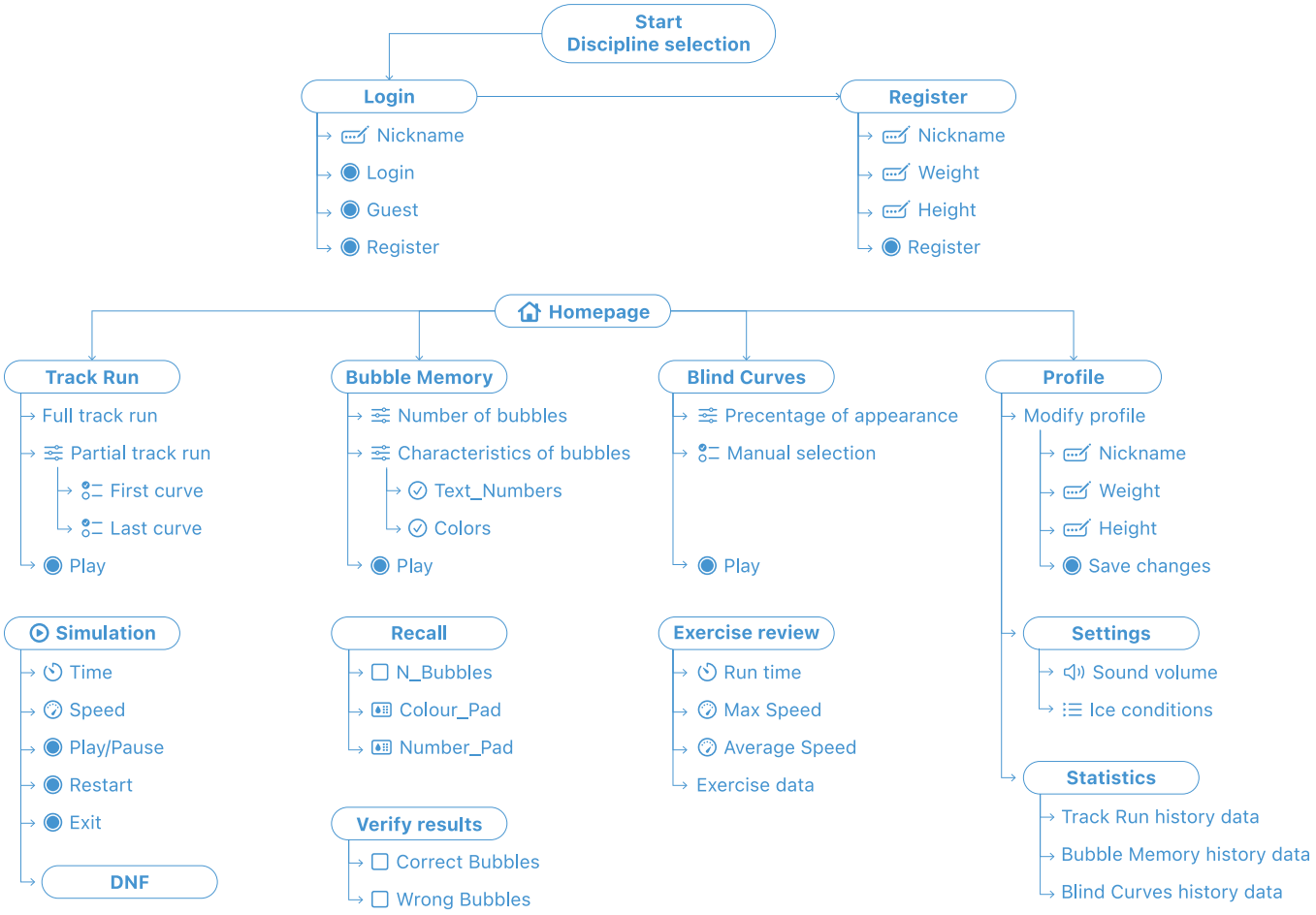


Fig.45: Information architecture scheme for the simulator system

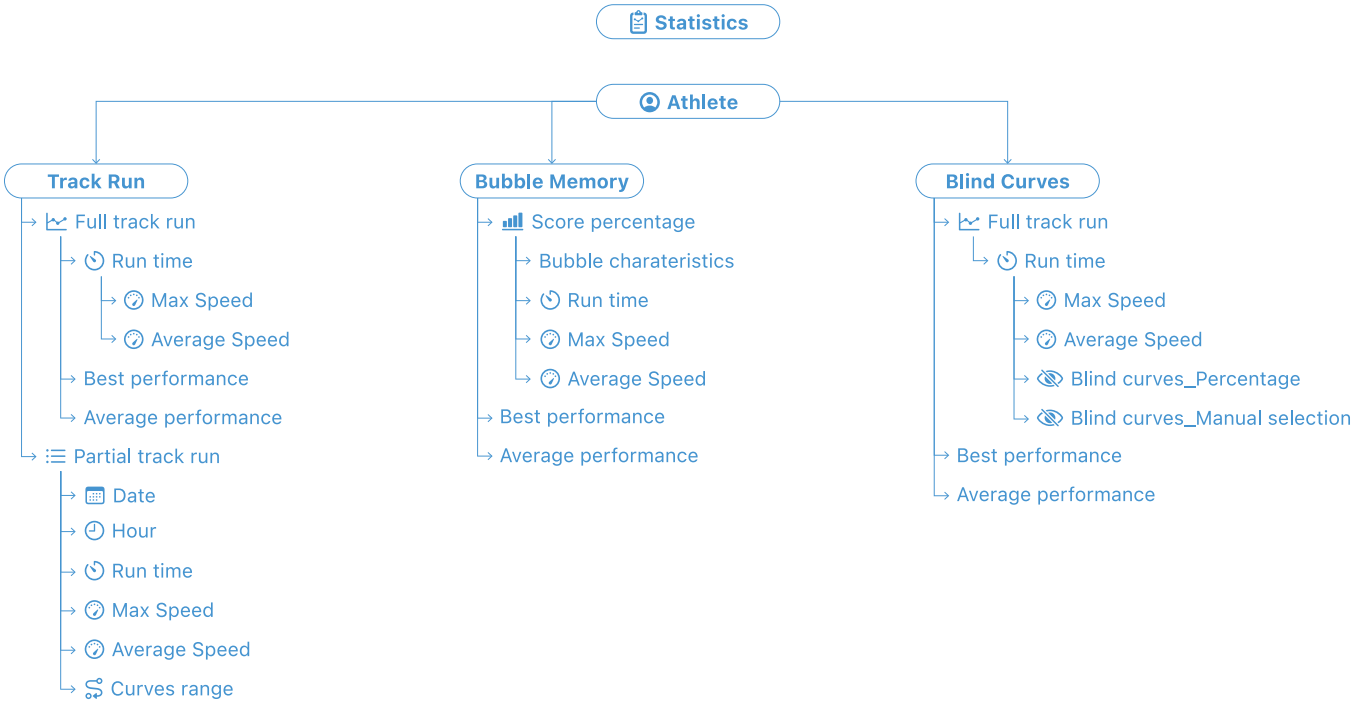


Fig.46: Information architecture scheme for the statistics section

The homepage is clean and intuitive, offering only the essential options of selecting the type of exercise or accessing the user profile.
Exercise settings are managed in the dedicated sections that are structured to allow clear and efficient modifications.
Each exercise leads to the simulation interface, which shows the pilot's point of view alongside additional information visible only in the computer, such as elapsed time and real-time speed. The user can also control the simulation directly by quickly and easily starting, pausing, restarting or ending the session.

At the end of each exercise, a summary screen displays the results achieved and the parameters selected for that session. All data is automatically saved and can be visualised later in the statistics section, where users can review and analyse their performance over time.

The statistics section is designed to enable users to review and analyse their performance data over time. Its structure reflects the different types of exercises included in the simulator. Since multiple training sessions can be performed in a single day, each exercise is automatically referenced by date and time. This enables users to navigate historical data via a calendar view. First, the interface prompts the user to select an exercise type, after which sessions can be filtered and compared chronologically. This organisation prioritises temporal classification over exercise-based grouping, offering a more intuitive understanding of performance progression (Fig.46).

In the Track Run module, full runs can be compared directly with each other to generate a historical graph, with each data point representing a descent. However, partial runs cannot be compared directly, so they are summarised in individual rows containing essential metrics such as speed, time and date. This allows for quick review and comparison.

In the Bubble Memory exercise, the main visual output is a graph showing the percentage error over time. Sessions are organised by date and time, and users can filter the results according to the characteristics of the bubbles, which are displayed by default in each exercise column.
As with the other exercises, the 'Did Not Finish' (DNF) data can be toggled on or off for clearer analysis.

The Blind Curves module uses the same logic as the Track Run visualisation to display completion time over time.

Overall, the Statistics section focuses less on direct numerical comparison between isolated sessions and more on identifying patterns and performance trends over time. Generally, a faster completion time indicates a higher degree of control, track familiarity and confidence,

allowing both athletes and coaches to monitor progress and make informed adjustments to their training routines.

5.3 WIREFRAMES

Once the information architecture had been defined, the next step was to create wireframes, simple graphical representations that organise and present information in an initial spatial and functional layout.

The literature emphasises the role of wireframes as low-fidelity representations that structure layouts and focus on critical functionalities (Sharma et al., 2019). Serving as blueprints, they help designers, developers, and other stakeholders to understand the placement of key interface elements, such as headers, buttons, navigation, and content blocks, without focusing on visual aspects, such as colours, fonts, or imagery (IxDF, 2016).

Wireframes bridge the gap between conceptual structure and visual design, enabling the layout established in the information architecture to be tested and refined before progressing to higher-fidelity prototyping. At this stage, clarity, hierarchy and interaction flow were prioritised over aesthetics or visual detail.

The focus is on how users should navigate through the system, access content and perform actions. Therefore, the wireframes visualise how each component, from the front page to the statistics dashboard, is arranged on the screen, showing navigation paths and the core functionalities of the all interface.

Fig.47: Graphical diagram of interaction between wireframe screens

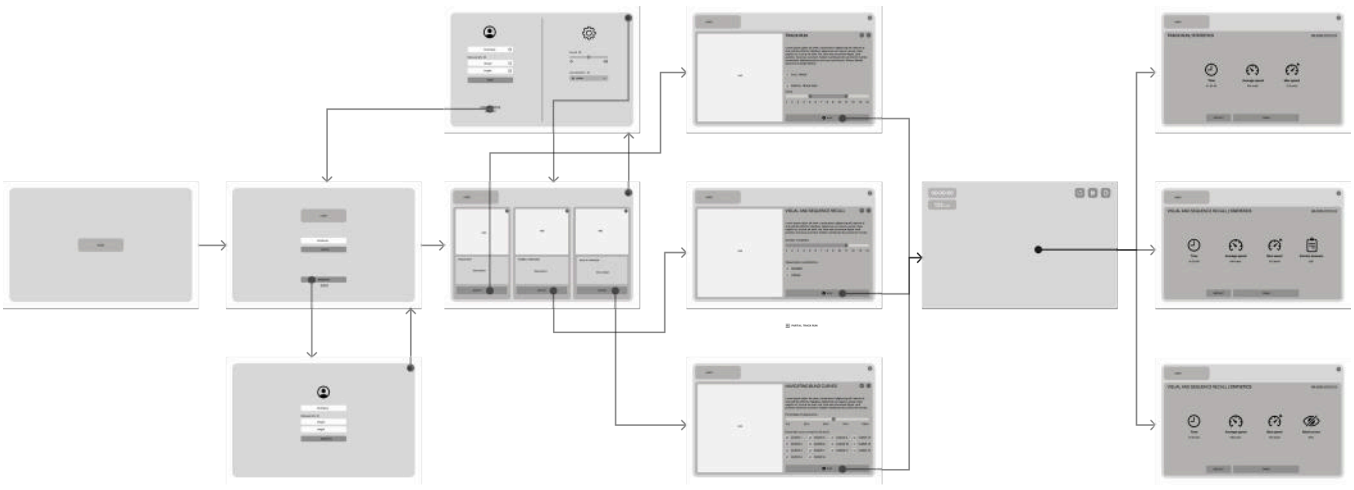


Fig.48: Homepage wireframe

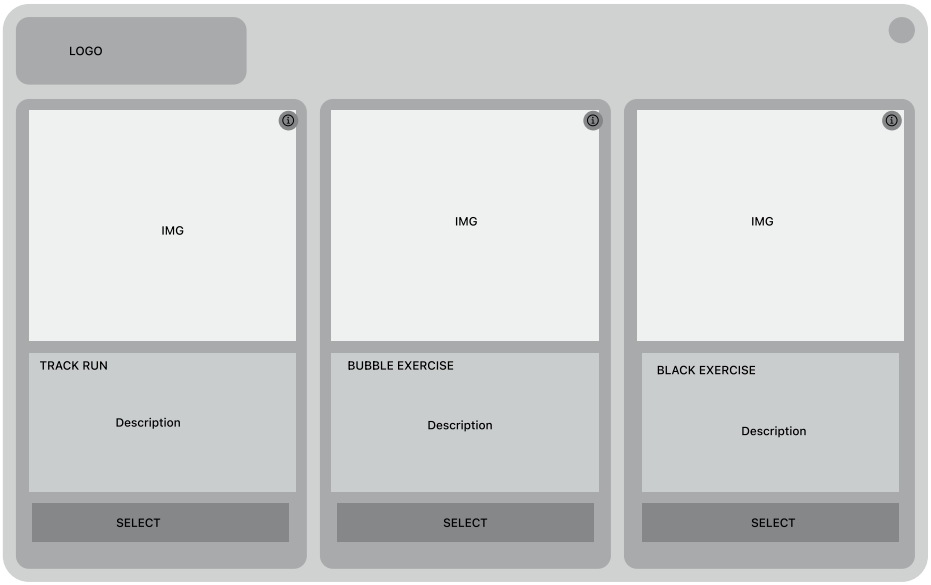


Fig.49: Track Run exercise wireframe

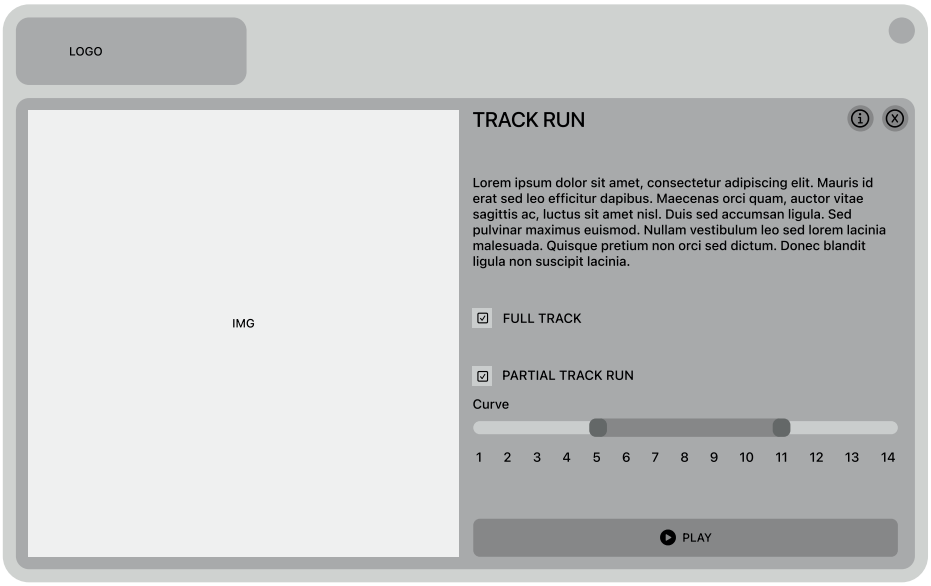


Fig.50: Post exercise recap wireframe



5.4 DESIGN SYSTEM

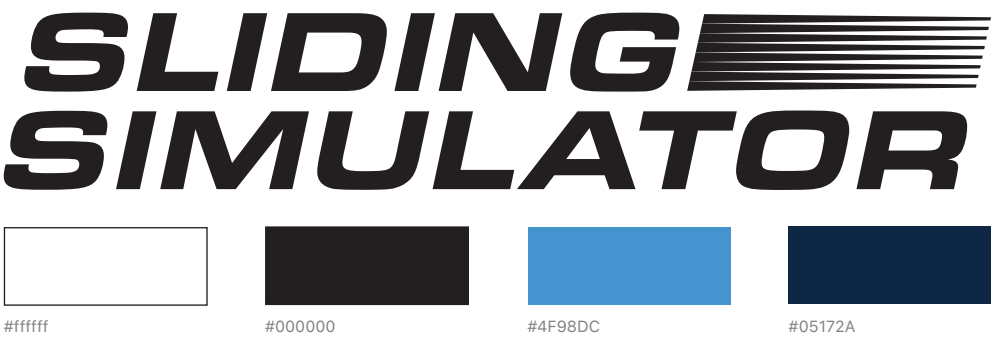
After structuring and organising the information with the help of wireframes, another important step in creating the complete interface was to design a consistent system. A design system can be defined as *"a complete set of standards intended to manage design at scale using reusable components and patterns."* (Fessenden, 2024).
A structured system that compiles all the visual and interactive elements of the interface, such as colour palettes, fonts, icons and reusable components, as well as their usage principles and interaction patterns. Creating a design system ensures uniformity, simplicity and scalability across all screens and user types, enabling the interface to maintain a consistent identity while adapting to different usage contexts.

The logo and name were designed to represent the sliding sports featured in the simulator: bobsleigh, luge and skeleton. The name *'Sliding Simulator'* was derived from this. The logo is a logotype set in Eurostile Black Extended Italic, a typeface chosen for its dynamic and aerodynamic appearance, which conveys a sense of speed effectively.
This concept is further emphasised by the graphic elements placed alongside the text. These elements are contained within a rectangular frame that defines the logo's structure and visual balance.

The colour palette comprises white, black and a light blue accent colour combined with darker shades of blue predominantly used for backgrounds. These colours were carefully selected to evoke the winter atmosphere and the icy surfaces typical of sliding sports.
The palette is applied using various levels of opacity to create visual depth and contrast across the interface.

In terms of typography, the interface uses the logo typeface, Eurostile Extended Italic, exclusively for titles and headings. SF Pro is used as the main typeface for all texts and graphical elements thanks to its clarity, legibility and versatility.

Fig.51: Logo and colours



Font: Eurostile Extended Black

ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890

Font: Eurostile Extended Regular Italic

ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890

Font: SF Pro Bold

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

Font: SF Pro Regular

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

Font: SF Symbols



Fig. 52: Interface modular grid: 8 columns, Gap: 24pt, Margin: 40pt

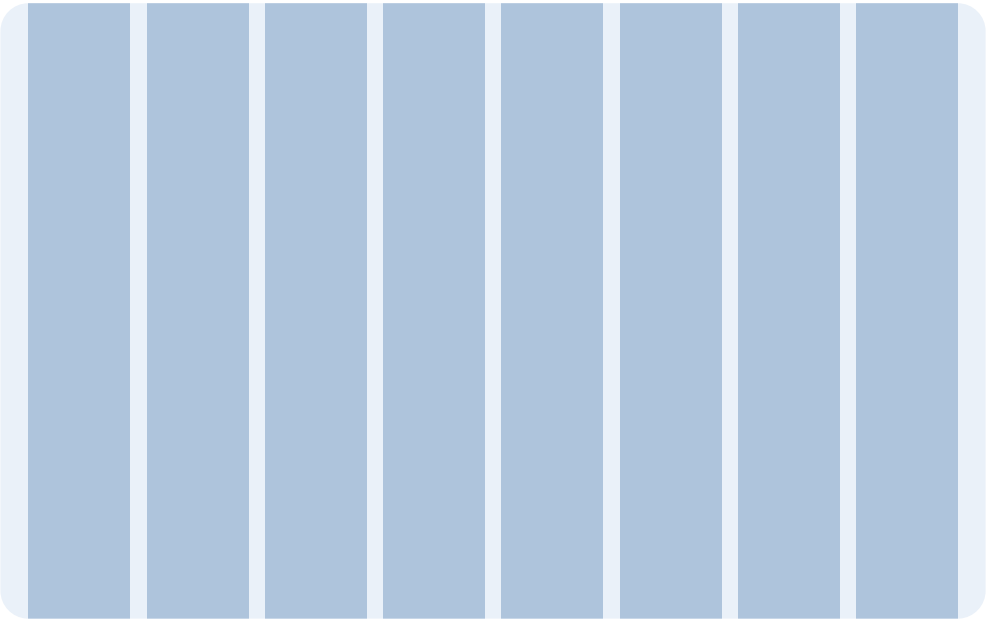
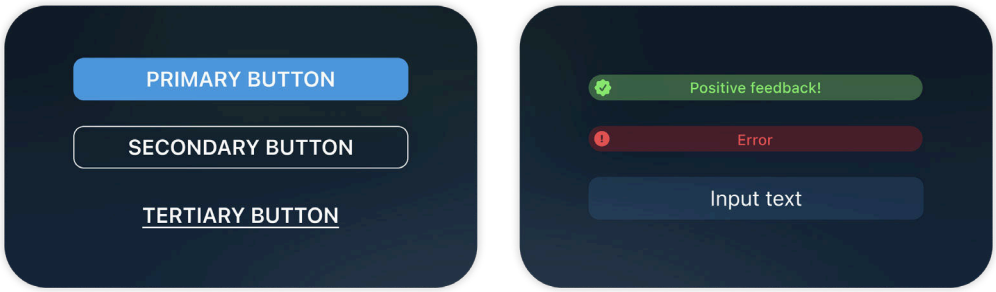


Fig. 53: On the left, the three types of buttons. On the right, the confirmation box, the error box and the input text



It is also important to highlight that the main body text is never smaller than 12 pt, ensuring optimal readability across different screens and viewing distances. Maintaining this minimum size supports accessibility and visual comfort, especially during prolonged use.

Icons and symbols are provided by SF Symbols 7, a library of over 6,900 vector symbols designed to integrate seamlessly with San Francisco, Apple's system font. These symbols are available in nine weights and three scales and automatically align with text, maintaining visual consistency across the interface (Apple Inc., n.d.). All icons follow standard UI design guidelines, with a default size of 24 pt, a 20 × 20 pt live area for the actual symbol, and 2 pt of padding around the edges.
This structure guarantees that icons maintain consistent proportions and visual clarity across various devices and resolutions.

Turning to the design system itself, three types of button have been defined, each serving a different communicative purpose. The primary button has a light blue background with white text and is used for main actions. The secondary button has a white outline and white text; the tertiary button consists of a simple underlined label that clearly indicates its interactivity while maintaining a minimalist appearance.

The input fields were standardised to ensure consistency across the interface. They are designed in the same way in the login and registration sections, as well as in the exercise-setup panels, to maintain a cohesive visual identity and a clear interaction model throughout the system.

Finally, a consistent layout grid was established to ensure visual harmony and structural coherence throughout the interface (Fig. 52).
Composed of eight columns, the grid features a 24 pt gutter and 40 pt outer margins, providing a balanced framework for the placement and alignment of all interface elements. All components adhere to a 4 pt spacing rule, meaning padding, margins and element dimensions are all defined in multiples of four. This approach guarantees visual consistency and rhythm, creating a clear, cohesive and intuitive interface.

Adhering to this modular grid system simplifies the design and development process and ensures scalability across different screen sizes and resolutions. Maintaining a predictable spatial structure gives the interface a professional and polished appearance while supporting usability and readability throughout the entire system.

These elements are consistently applied across every screen to clearly communicate the importance, hierarchy and function of each action. Layout, typography and iconography are kept coherent to guide users naturally toward the most intuitive interaction paths.

5.5 SLIDING SIMULATOR INTERFACE

The development of user personas, information architecture and a design system, together with the user tests described in *Chapter 7*, led to the development of the final interface presented in this section.
The following section provides an in-depth overview of each screen, outlining the interface design, structure and interaction logic that shape the user experience throughout the system.

It should be noted that each exercise has a set of variables that determine its difficulty level. These variable ranges are designed for the training needs of professional pilots, but can also be modified to provide very simple or very complex training routines, depending on the user's desired outcome and experience level.

For clarity, the interface has been organised into four main categories, each representing a distinct phase of interaction within the simulator:

- *Access & Onboarding*, which includes the Start, Login, Register and Profile. These are dedicated to user entry and basic configuration.

- *Training Experience*, which includes the homepage, the three exercise setup sections and the simulation interface. This is the core of the training setup where interaction and simulation occur.

- *Performance Review*, which includes the recap screens for each exercise and the recall section of Bubble Memory (the input selection and the verified results). This is the section of the feedback summary provided upon completion.

- *Statistics*, which includes the historical data section, allowing users to review exercise runs, analyse progress and identify performance trends over time.

This structure mirrors the logic of the training process itself, from access and preparation to real-time simulation and post-exercise reflection, through to long-term data analysis, ensuring a coherent and progressive user experience across the entire platform.

5.5.1 Access & Onboarding (Start, Login, Register, Profile)

The *Start* page is the first screen displayed to the user. Here, the simulator's logo is displayed alongside the discipline selection.
This is a key decision that determines the type of users involved and the point of view within the virtual environment.
The development so far has been focused on the bobsled discipline,

but the interface has the capacity to support the implementation of the other two sliding disciplines. Each discipline is represented by a custom icon showing the athlete's position on the sled, which makes the choice easy to understand, even for less experienced users.
It is also possible to set the simulation mode using the VR toggle.
By default, it is set to 'off' because the system is primarily set up for a screen. If it is checked, the simulation can be performed in VR.

The next screen is the ***Login*** page, which contains a simple nickname input field and a primary button for logging in.
From here, users can log in, register a new profile or enter as a guest.

Fig.54: Page: Start

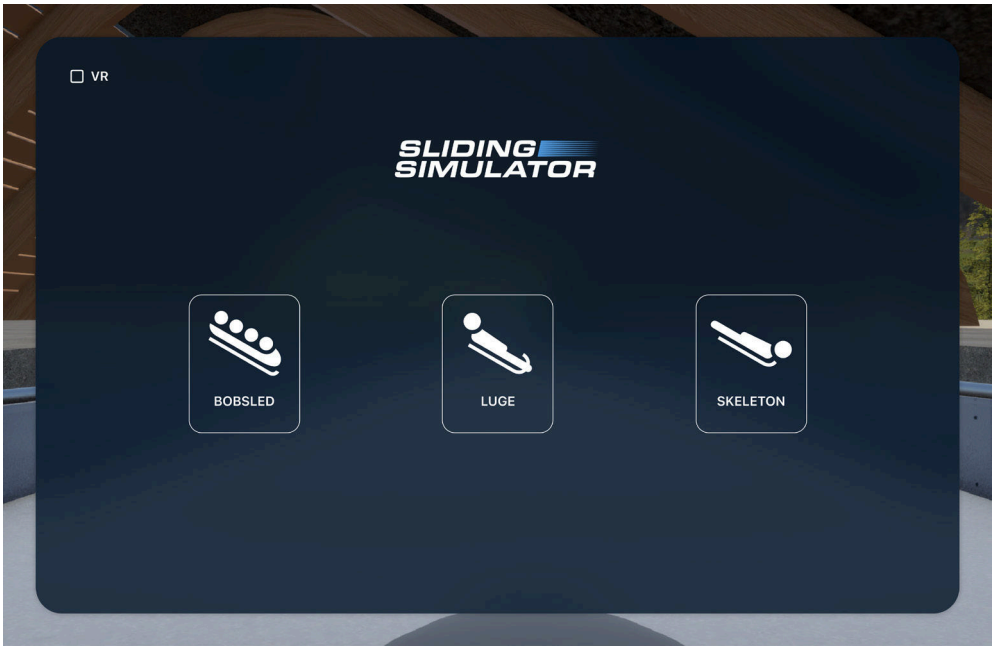
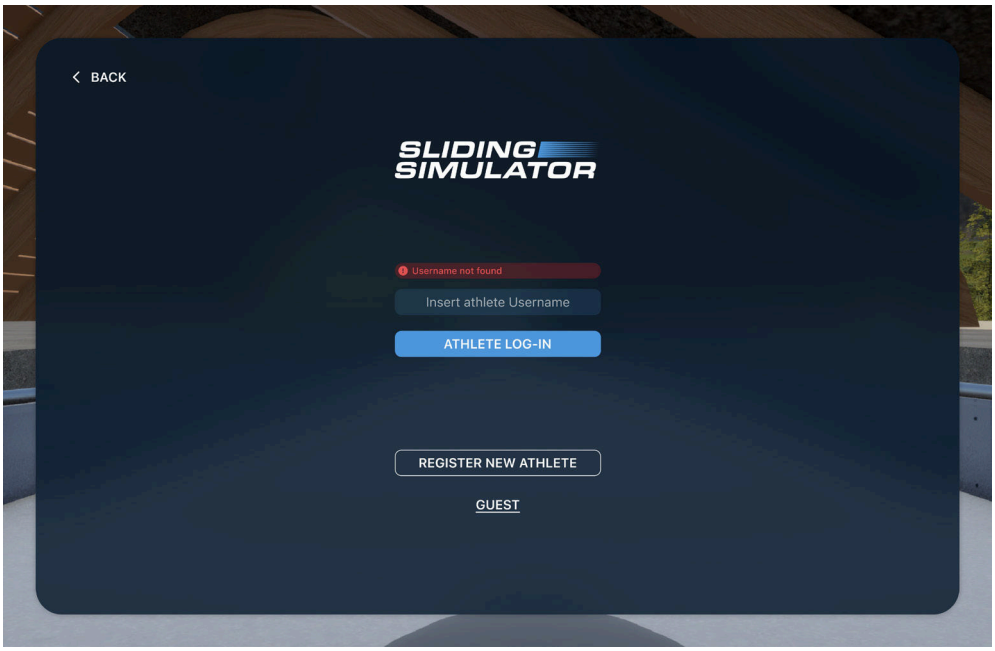


Fig.55: Page: Login with an example of possible error



The interface is intentionally clear and intuitive, with red error banners appearing whenever incorrect or incomplete information is entered to guide the user through the process.

If the user has not been registered before, they can navigate to the *Registration* page where they must enter basic information to generate their profile. This screen explicitly communicates that the registration process is intended for the athlete. The interface also explains why certain personal data is required, explaining the connection between physical characteristics and the personalised simulator setup.
This screen error banner also appears at the top of the first input box.

Fig.56: Page: Register

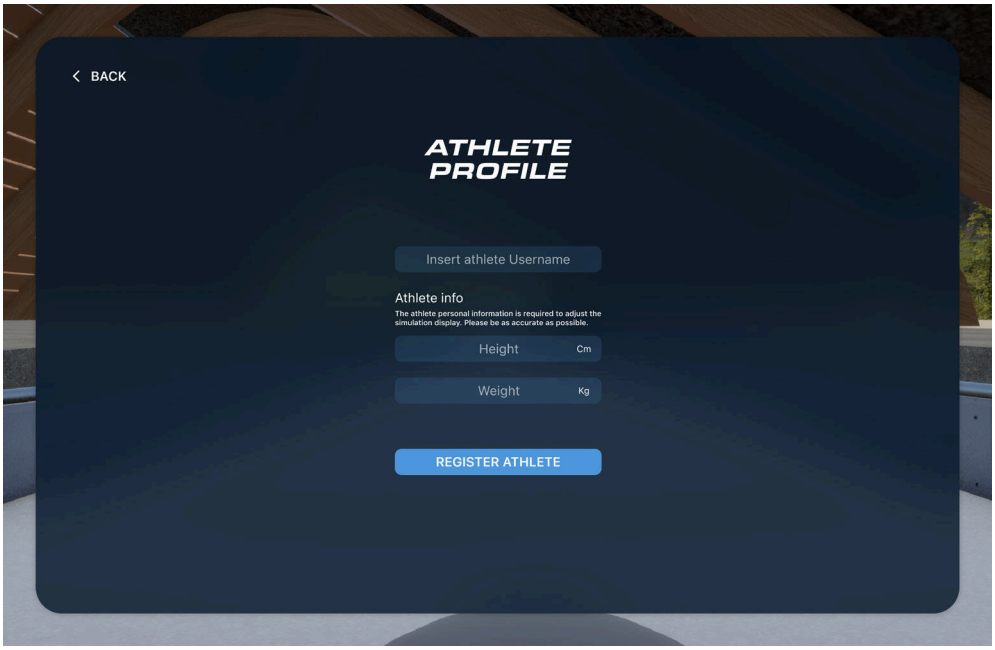
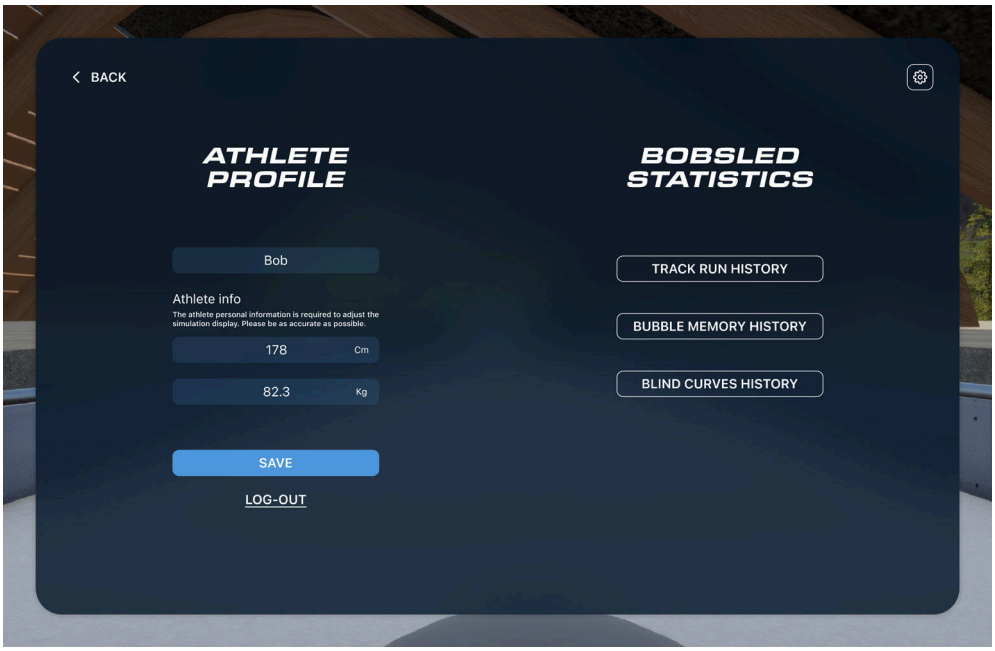


Fig.57: Page: Profile



Finally, the *Profile* screen contains all the fields that were initially required during registration. This allows users to edit and save their personal information, and log out of the system. Once the updated information has been saved correctly, a green message confirming that the modification has been made will appear at the top of the first input box. The profile also provides direct access to the statistics pages, which are organised by exercise type, enabling users to quickly review their performance data. This section also includes the settings panel, where users can adjust parameters such as the volume of ambient sounds and ice conditions, choosing between winter, autumn or spring.
These environmental settings affect the physical interaction between the bobsleigh and the track surface, simulating the influence of different seasonal temperatures on friction and overall performance.

5.5.2 Training Experience (Homepage, Track Run setup, Bubble Memory setup, Blind Curves setup, Simulation screen)

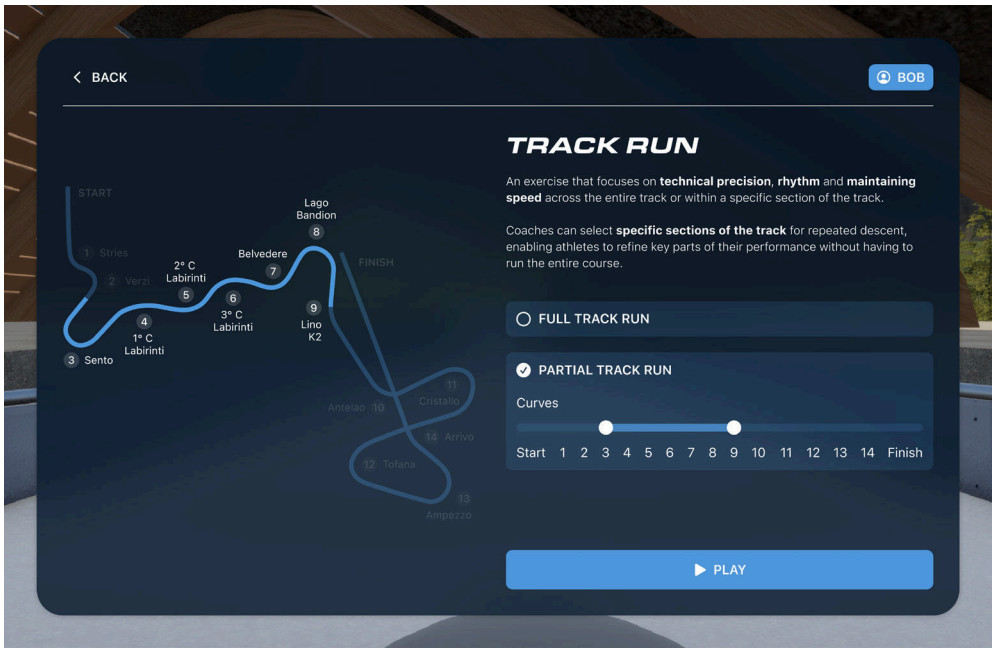
As previously described, each exercise includes a set of key parameters that can be customised by the user. Additionally, each exercise features a graphical preview that provides an overview of what will happen during the simulation. When a track is involved, the curves are identified by name and a number, as the Cortina Sliding Centre is the only track that classifies its turns by name. This naming convention makes it easier for athletes and coaches alike to identify and define specific exercises.

The *Homepage* provides the most direct and user-friendly access to the simulator's functions. Three large cards are displayed, each describing one of the available exercises. Textual and graphical elements illustrate their main characteristics.

Fig.58: Page: Homepage



Fig.59: Page: Track Run Setup

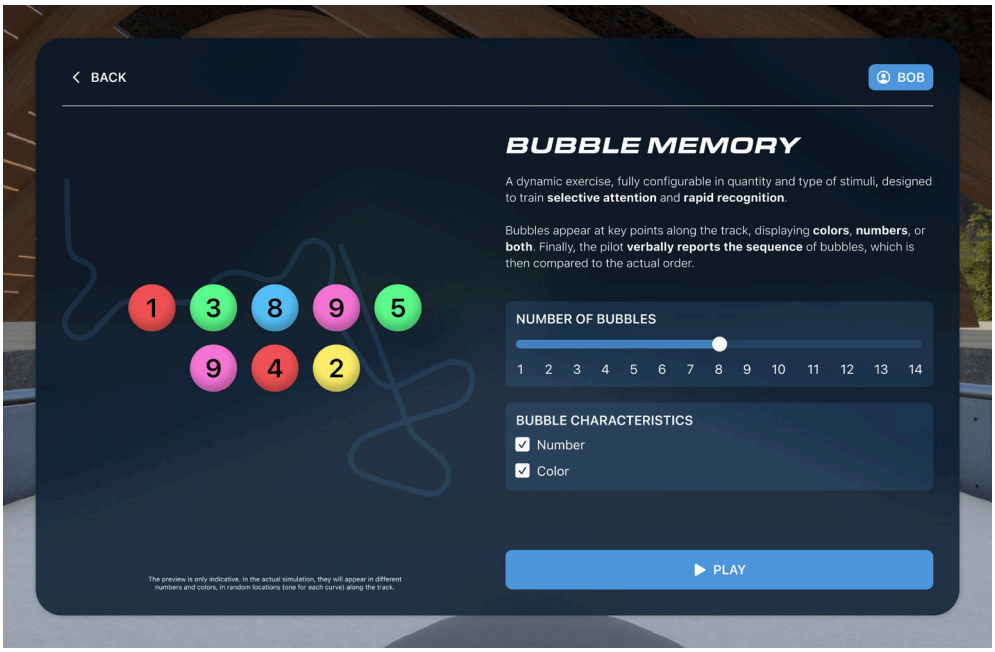


Keywords at the top and bold text in the description make the aim and goal of each exercise clear from the outset.The profile button, which is not visible in the guest login, is customised with the user's nickname and is designed to accommodate longer names, ensuring clarity and consistency across all profiles. If the user logs in as a guest, the Profile section is inaccessible and run data is not saved. The Profile button is replaced by an Exit button that takes you back to the Start page.

In the first exercise setup screen, *Track Run*, users can choose between two modes: Full Track Run and Partial Track Run. Selection is made via exclusive toggle buttons (activating one automatically deactivates the other). When 'Partial Track Run' is selected, a two-handle slider becomes active, allowing users to select the starting and ending curves of the desired training segment. The section of the track that the user will experience begins at the start of the first selected curve and ends at the start of the first excluded curve. The decision to keep the sliders visible even when inactive stems from the need to make the available customisation options immediately clear and visually accessible.
In this interface, the preview changes according to the selected option. For a full run, the entire track is displayed, while for a partial run, the preview dynamically adapts to the selected range on the slider, highlighting or disabling the corresponding segments.

The configuration for the *Bubble Memory* exercise consists of two main parts. The first slider determines how many bubbles will appear randomly at the 14 predefined points along the track.
Below, two toggles define the charatteristics of the bubbles, specifying whether they will display a colour, a number, or both.

Fig.60: Page: Bubble Memory Setup

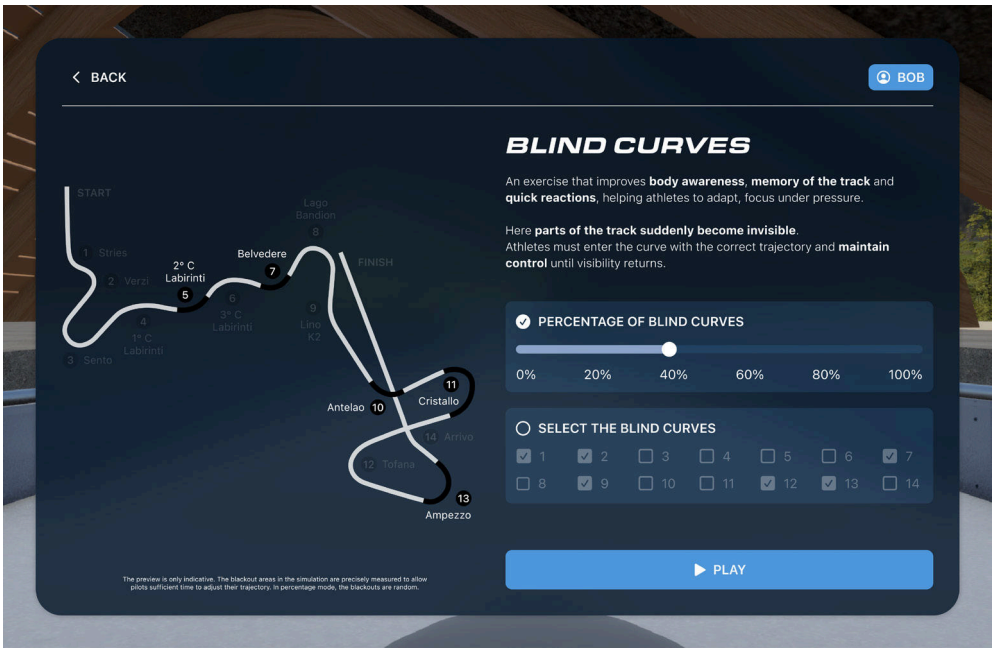


In this case the appearance of the bubbles is random, meaning users cannot choose where they will appear on the curves.
This design choice is intentional: even when a bubble is not visible in a given section, the pilot will instinctively continue to search for it, scanning the track and identifying potential reference points. This ensures that the exercise remains cognitively challenging throughout the entire descent, encouraging constant visual attention and spatial anticipation rather than passive observation.

The reference points are positioned at the start of the wooden part of the curve, but can easily be modified via the Unity scene setup.
The preview shows the number and type of bubbles selected, and includes a note clarifying that *"The preview is only indicative. In the actual simulation, they will appear in different numbers and colors, in random locations (one for each curve) along the track."*.

As in the first exercise screen, the *Blind Curves* setup screen offers a choice between two modes: random or manual blackouts.
The selection is made via exclusive toggle buttons. The first toggle refers to the random blackout selection and activates a slider that defines the percentage of curves that will be obscured along the track.
For clarity, it includes both 0% and 100% values, ensuring the information is understandable to all users. If the 0% option is selected, the pilot will experience a basic full track run. If the 100% option is selected, all the curves will be obscured, meaning that the pilot will only be able to see the straight sections and the junction segments.
Alternatively, the user can manually select which curves will be blacked out, a useful feature for designing targeted training sessions.

Fig.61: Page: Blind Curves Setup



The preview shows the track and highlights the sections that can be obscured according to the selection. It also specifies that: *"The preview is only indicative. The blackout areas in the simulation are precisely measured to allow pilots sufficient time to adjust their trajectory. In percentage mode, the blackouts are random"*.

Finally, when the user clicks the most prominent element on each setup screen, the Play button, the simulation begins simultaneously on the curved screen and the control interface, which is visible to the coach.

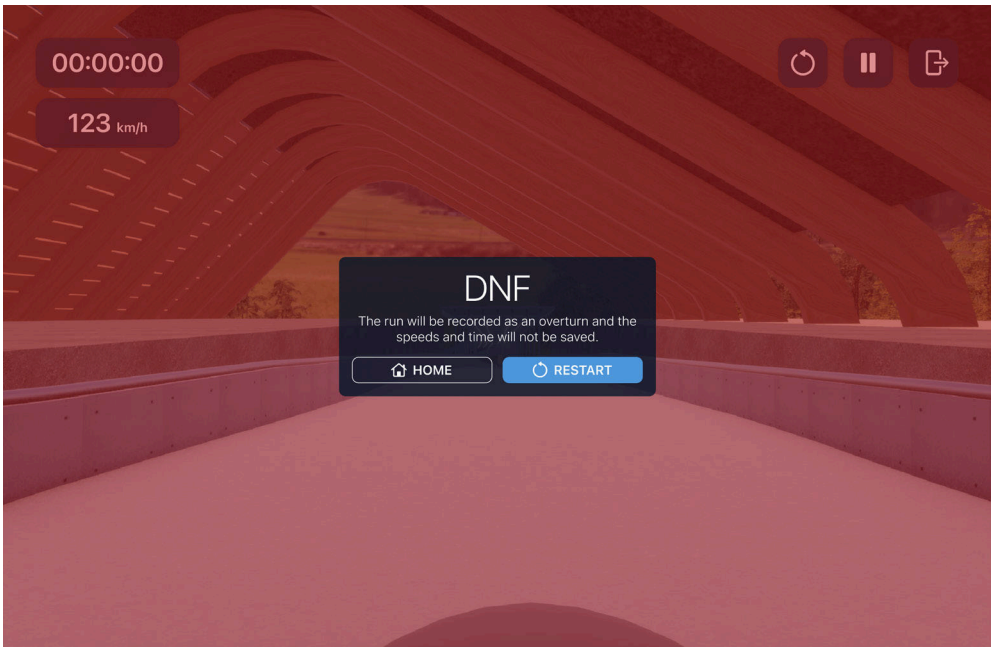
The *simulation* UI on the pilot curved screen is absent while on the computer it displays real-time data and key control buttons.
In the top-left corner, elapsed time and current speed are displayed, and in the top-right corner, three buttons allow the coach to efficiently manage the simulation session. These are the reset button, which allows you to restart the simulation from the spawn point; the play/pause button, which changes the icon when pressed; and the exit button. Each button displays a clear and specific icon that describes its function without the need for a label.

This interface also includes two specific screens.
The *DNF (Did Not Finish) screen* appears when the sled overturns or leaves the track. The main option is to restart, while the secondary option is to go back to the homepage. The screen also explains how the performance data will be saved. The *Exit screen*, which appears when the Exit button is pressed, allows the user to decide whether to save the data, even if the run is not completed. This useful function enables developers and coaches to make the exercises more adaptable and

Fig.62: Page: Simulation



Fig.63: Page: Simulation DNF

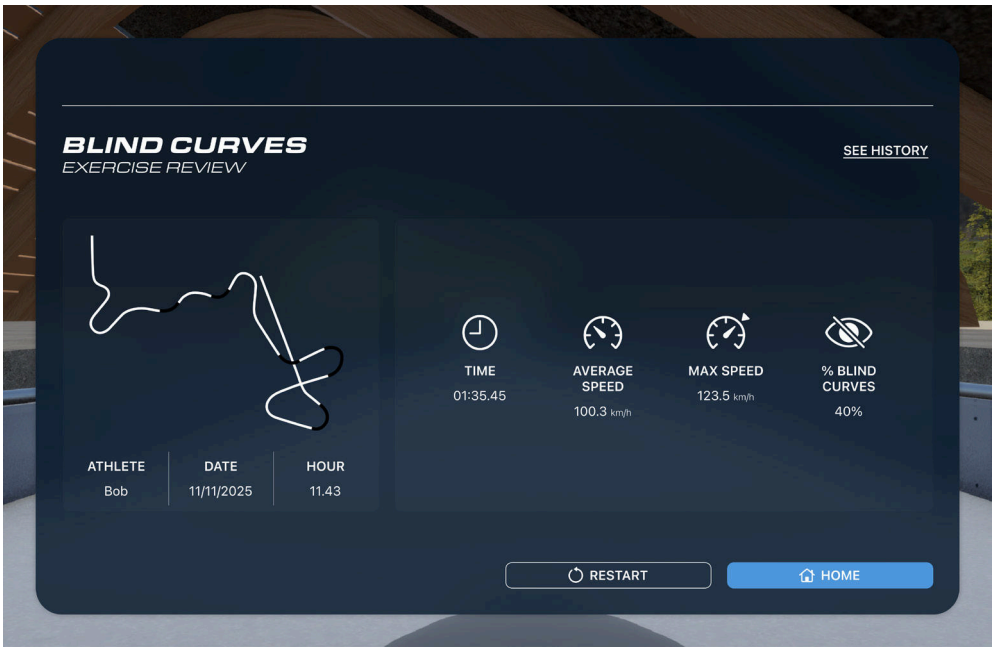


dynamic, and to customise the repetition of specific sections for targeted practice. If the user chooses to save the data, it will be visible on the exercise's stats sheet, but not on the statistics page.

5.5.3 Performance Review (Post-Exercise recap, Bubble Memory Recall, Bubble Memory Results)

Moving on to the post-exercise screens, these display the main performance data recorded during the descent simulation.
Data, hour, time, average speed and maximum speed are shared across all three exercises, while each exercise also includes parameters specific to its unique focus.

Fig.64: Page: Blind Curves exercise review



The summary of the *Partial Track Run* includes the range of completed curves and a brief visual overview.

The *Bubble Memory* summary exercise screen shows the characteristics of the bubbles and the number of bubbles correctly identified out of the total seen. This is further clarified by a visual representation showing where the bubbles appeared on the track and which were correct.

For the *Blind Curves* exercise, it specifies the number of curves blacked out during the run. Here, too, the review is clarified by a simple visual reference showing which curves were blacked out.

This ensures that both the exercise setup and the athlete's performance are clearly summarised at the end of each session. Each parameter is accompanied by an explanatory icon designed to make the data immediately recognisable in the statistics section, so that textual labels are not needed. All units of measurement are consistent with those used in competition measurements (time in milliseconds and speed in kilometres per hour). The other buttons on the screen allow the user to perform the main navigation tasks and view historical and performance data relating to the specific exercise (via the 'See History' button).

In the case of the *Bubble Memory* exercise, users encounter a recall screen before reaching the final review screen, where they must reconstruct the sequence of bubbles seen during the simulation.
The idea is that the coach uses the control computer to ask the pilot to recall the characteristics of each bubble, colour and/or number, and enters them into the system.

Fig.65: Page: Bubble Memory Recall

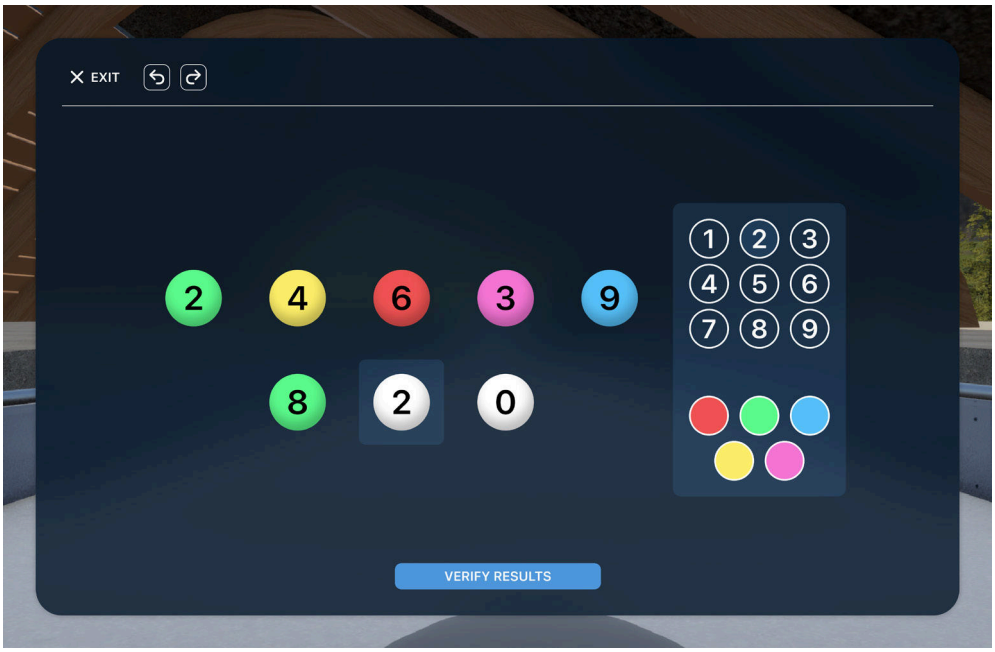
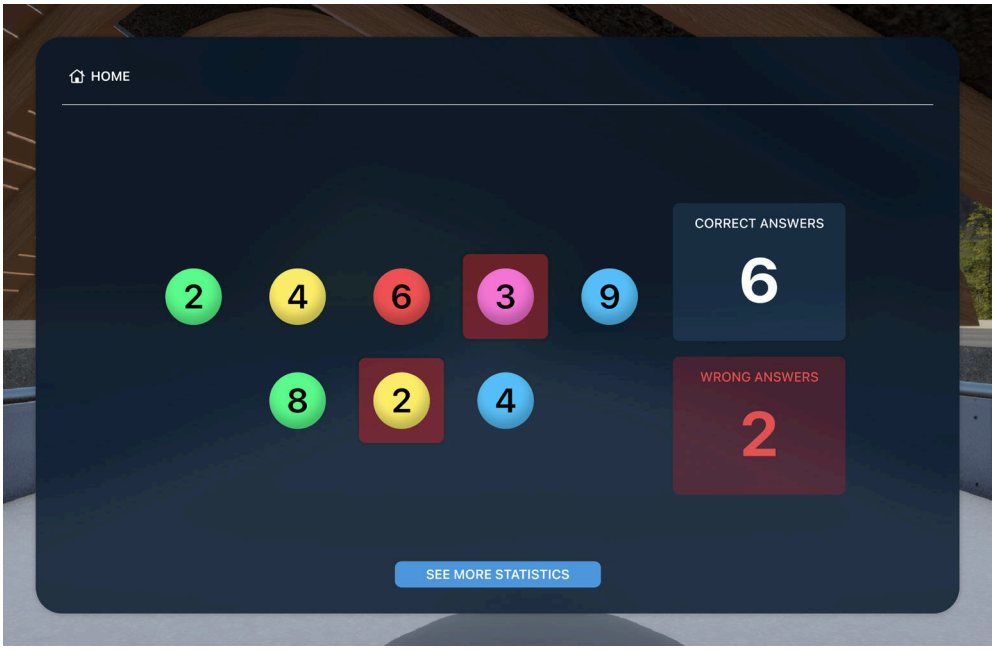


Fig.66: Page: Bubble Memory Results



This process is facilitated by a set of bubble slots equal to the number displayed during the simulation, as well as two keypads: one for entering numbers (1–9) and one for colours (five main options).

Depending on the initial setup, the interface adapts dynamically, for instance, if the bubbles were defined to show only numbers, the colour keypad will not appear. Users can modify the bubble inputs freely by selecting them directly and navigate through the sequence using the arrow buttons in the top left corner of the screen. The interaction is designed to make the selected bubble clearly identifiable by highlighting its background, providing immediate visual feedback.

To streamline the input process, once a bubble has been completed, the selection automatically moves on to the next one.
This process reduces unnecessary clicks, improving the overall efficiency of the interaction.

Once all responses have been entered, the main action button enables the coach to verify the results. The following review screen displays all the bubbles that have been recalled, highlighting the incorrect answers with a red background. Hovering over an incorrect bubble reveals the correct answer, enabling both the coach and the athlete to understand the nature of the mistake and reflect on the cognitive aspect of the task. Initially, the menu above the main elements displays the exit button, enabling easy navigation between the options. However, after verification, the button only allows the user to return to the homepage. This screen is followed by the post-exercise review screen described at the beginning of this section.

5.5.4 Statistics (TrackRun statistics, Bubble Memory Statistics, Blind Cuves statistics)

The Statistics section can be accessed either through the Profile page or via dedicated buttons on the Post-Exercise Review screens.
Historical data is organised by exercise type and visually represented through graphs designed to highlight performance trends over time.

Each statistics screen includes a calendar component that allows users to navigate through past sessions and select the days or periods on which a specific exercise was performed. There is also a DNF (Did Not Finish) toggle, which enables users to include or exclude incomplete runs, for example, if the sled overturned. This feature helps to display overall progress more clearly without necessarily visualising errors made during failed attempts. All charts can be scrolled horizontally or vertically depending on the layout of the information presented.

Starting with the *Track Run* section, the statistics are divided into two separate views: *Full Track Runs* and *Partial Track Runs*.
This distinction is necessary because partial runs cannot be compared unless the same curve range is selected.

For *Full Track Runs*, a line chart has been designed with date and time on one axis and descent time on the other (time is the primary metric used to determine performance in real competitions).
Hovering over each data point, which represents a specific session, reveals additional information, such as the average and maximum speeds.
To the right of the chart, there are three boxes displaying, respectively, the best run, the average values, and the selected run.
When a column is selected, its data appear in the last box, allowing for

an easy comparison with the information shown in the pop-up that appears when hovering over the other data points.

The *Partial Track Run* page is presented as a vertical list instead, with the most recent performance displayed at the top. Each row summarises all relevant performance metrics, which can easily be compared as they are aligned within the same visual structure. To the right of the list, there are two boxes. The first one is generated after selecting a range of curves: if the user selects a specific row, a chart is displayed comparing all the runs completed within that curve range, along with the average performance values for that specific segment. If no row is selected, the

Fig.67: Page: Full Track Run statistics

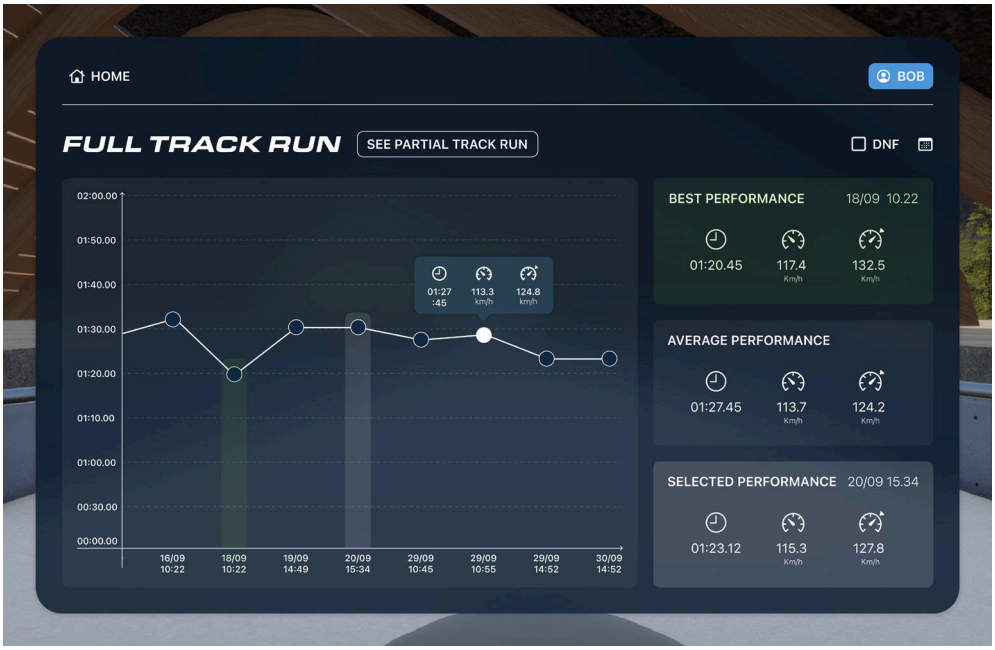


Fig.68: Page: Partial Track Run statistics

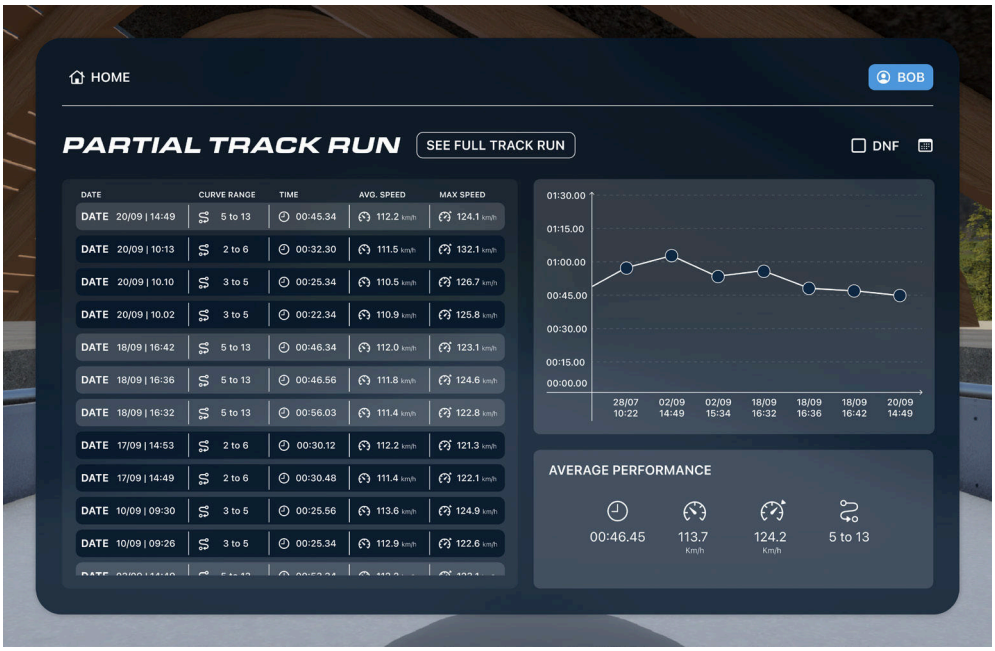


Fig.69: Page: Bubble Memory statistics

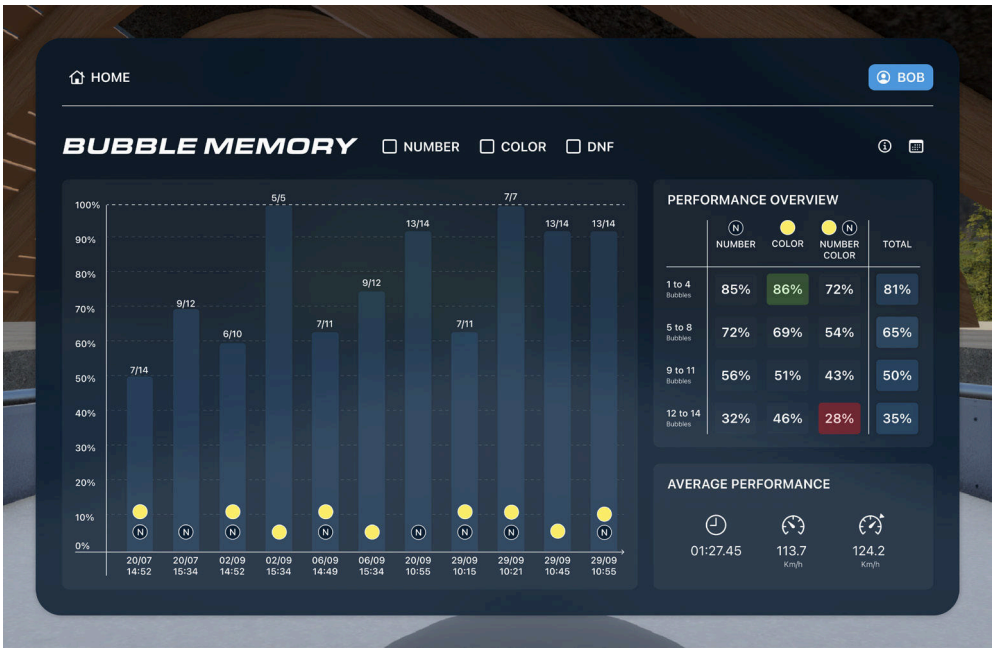


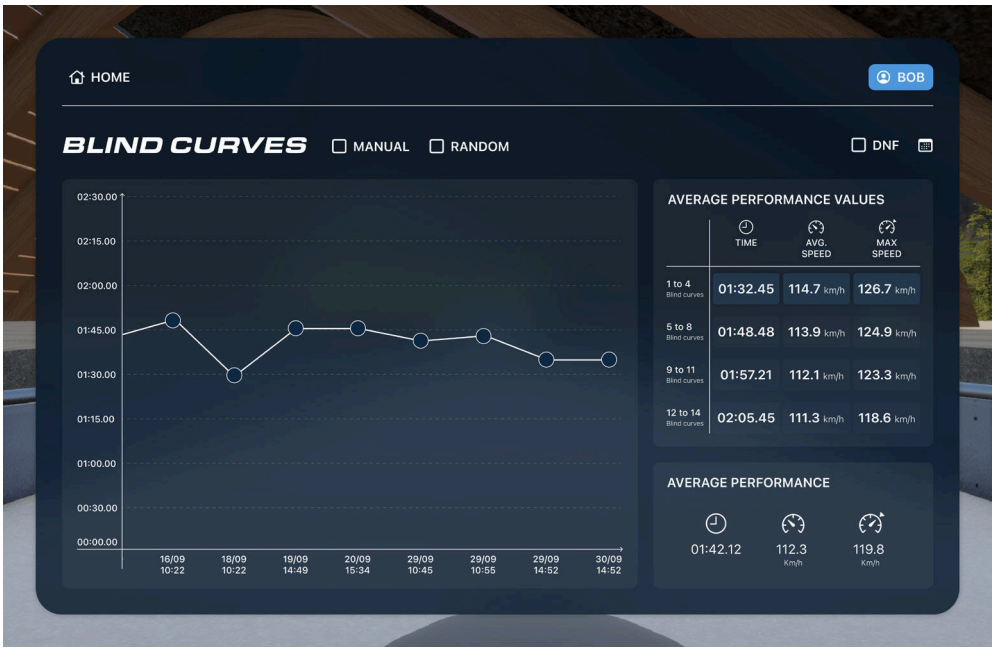
chart remains empty, and the average performance data refer to all the runs completed overall. A secondary button positioned near the title makes it easy to switch between the two sections.

For *Bubble Memory*, the only absolute and comparable metric between sessions is the percentage accuracy of recalled bubbles. This data is represented by a column chart, with the date on one axis and the percentage of correct answers on the other. Each column represents a session. At the top, it shows the number of bubbles used, and at the bottom, it includes small icons that indicate the type of bubbles used during that run. Results can be filtered more easily for comparison using three toggles, which allow users to include or exclude runs featuring numbers, colours, or both. The decision not to show descent parameters in this case stems from the fact that the exercise is based on memory and finding reference points. The data related to the descent are still saved and available in the save file for the exercise.

To the right of the chart, the overall percentages of correct answers are displayed, divided by bubble type and by the number of bubbles placed along the track. Four macro-categories were created to group different bubble quantities, providing more consistent and meaningful data. As in previous cases, average performance values are shown below the chart.

Finally, the *Blind Curves* graph has the same structure as the Track Run chart. However, the hover pop-up for each data point also shows the number of blacked-out curves in that session. In this case, on the right side, the average run data are displayed and organized according to the number of obscured curves, providing an overall overview. Below, there

Fig.70: Page: Blind Curves statistics



is a box showing the average performance, which changes to selected performance when a column is selected, allowing for comparison as in the first track run chart. Additionally, two filter toggles have been added to include or exclude runs based on whether the curve selection was manual or random.

5.5.5 Conclusions

In conclusion, the simulator's interface has been carefully designed to provide a coherent, accessible and progressive user experience that mirrors the logic of real athletic training, from initial access and setup to simulation, performance review and long-term data analysis.
Each screen has been developed with a strong focus on clarity, usability and consistency to ensure that users can navigate the system intuitively and focus entirely on their training objectives.

The interface adapts to different levels of expertise, from beginners to professional pilots, by integrating customisable exercise parameters, dynamic previews, and context-specific feedback, while maintaining a unified visual and interaction language. The modular design system allows each component to communicate clearly within the overall framework, supporting both functional efficiency and perceptual coherence.

Ultimately, this interface does more than simply visualise training data; it connects athletes, coaches, and the system, providing a single, seamless experience. It enhances understanding, fosters engagement and ensures the simulator operates as a comprehensive, intuitive training ecosystem for cognitive and physical performance development, not just a technical tool.

6.

IMPLEMENTATION IN UNITY

This chapter outlines how the developed elements are implemented in Unity. It begins by explaining how a block diagram maps screens, actions and scripts, providing guidance for a Unity architecture that enables seamless navigation and performance.
It then details the implementation process, from Figma exports (sprites, fonts and 3D assets) to the organisation of the Unity project hierarchy. Scripts are explained and grouped into eight categories: Core, Service, Physics, UI, TrackRun, BubbleMemory, BlindCurves and History.
Finally, it provides a theoretical comparison of curved-screen and VR modes, highlighting their differing ergonomics, display constraints and calibration needs.

6.1 BLOCK DIAGRAM AND LOGIC DESCRIPTION

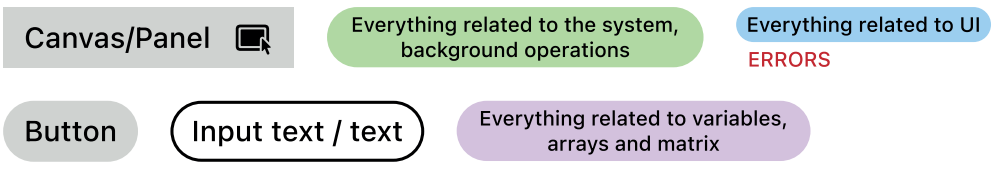
Having designed and prototyped the full interface in Figma, the next step was to implement it in Unity. Unity is a cross-platform game engine that provides a comprehensive environment for developing 2D and 3D interactive experiences. Built on a component-based architecture, it allows developers to create *GameObjects* (the fundamental entities within a scene) which acquire functionality through components such as *Transform* (which defines position, rotation and scale), *MeshRenderer* (which manages visual appearance), *Rigidbody* (which enables physical behaviour) and *Script* (which contains custom logic). Developers implement interactive behaviours using C# scripts. The Unity Editor supports real-time scene editing, debugging and asset management. Rendering can be performed using the Built-in Render Pipeline, the Universal Render Pipeline (URP) or the High Definition Render Pipeline (HDRP), depending on the project's visual and performance requirements.

To better understand the logical and computational relationships between screens, actions and scripts, a block diagram was developed. This diagram serves as a conceptual map of how the interface communicates with the underlying system, clarifying the flow of actions, variables, and user inputs throughout the experience.

The diagram is organised into multiple sections to improve readability and highlight the application's modular structure. Each section corresponds to a specific functional area, such as authentication, exercise management, data visualisation and statistics, showing how information and control are transferred from one component to another.
Colour coding and grouping help to distinguish between user interface operations, variable and data management, and background system logic, as can be seen in the diagram legend.

From a structural perspective, the system is designed to operate entirely within a single Unity scene. Rather than loading different scenes for each exercise, all interface elements coexist in the same environment and are activated or deactivated according to the user's navigation.

LEGEND:



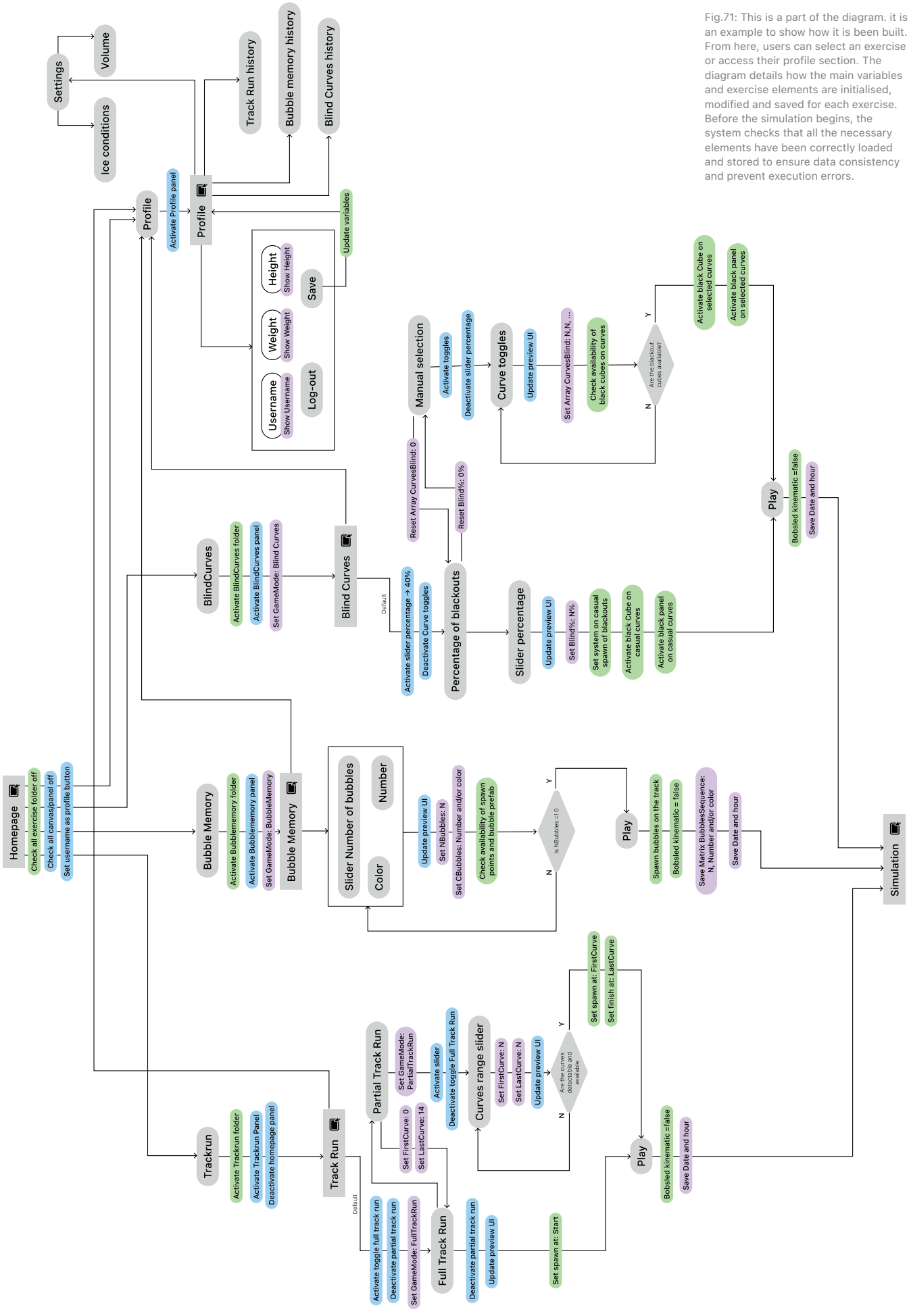


Fig.71: This is a part of the diagram. it is an example to show how it is been built. From here, users can select an exercise or access their profile section. The diagram details how the main variables and exercise elements are initialised, modified and saved for each exercise. Before the simulation begins, the system checks that all the necessary elements have been correctly loaded and stored to ensure data consistency and prevent execution errors.

This solution minimises loading time, improves performance and ensures seamless transitions between exercises and menus. When a user accesses an exercise, the corresponding panel and its control scripts are enabled while all other elements are temporarily disabled.
The same logic applies to the log-in, registration and profile management panels, which adapt dynamically to the user's status (guest or registered athlete).

Each exercise follows a coherent structure: it retrieves stored data from JSON files, updates the relevant variables during the simulation and saves the results once the session ends. This ensures a continuous flow of information between the user interface and the data layer, maintaining consistency across the whole system.

This diagram was crucial for clarifying the system's overall structure and defining its foundational logic. This framework was later refined and adapted according to practical requirements encountered during implementation, as described in the following section.

6.2 IMPLEMENTATION OF ELEMENTS AND SCRIPTS

The implementation process began by exporting all interface elements from Figma as .png images. This allowed them to be imported into Unity as 2D sprites and applied to the existing UI components within the software. Some assets were imported using the *Mesh Type: Full Rect* setting, ensuring they could be applied to UI elements of various sizes while maintaining visual consistency and graphic quality.
All assets were organised into folders to facilitate easy navigation and replacement when necessary. Similarly, materials and 3D models were organised into dedicated folders and a new directory was created specifically for scripts.

After importing the visual assets, the next step was to add the typefaces (Eurostile and SF Pro in all weights) and recreate each interface screen by rebuilding its main components one by one. These screens were then grouped into folders according to their respective exercises.

The 3D elements used in the simulation, such as the training track components and the bobsleigh model (represented in Unity by a capsule), were added and placed in the relevant exercise folder.

Another key step was to position the simulation camera correctly in relation to the bobsleigh capsule.

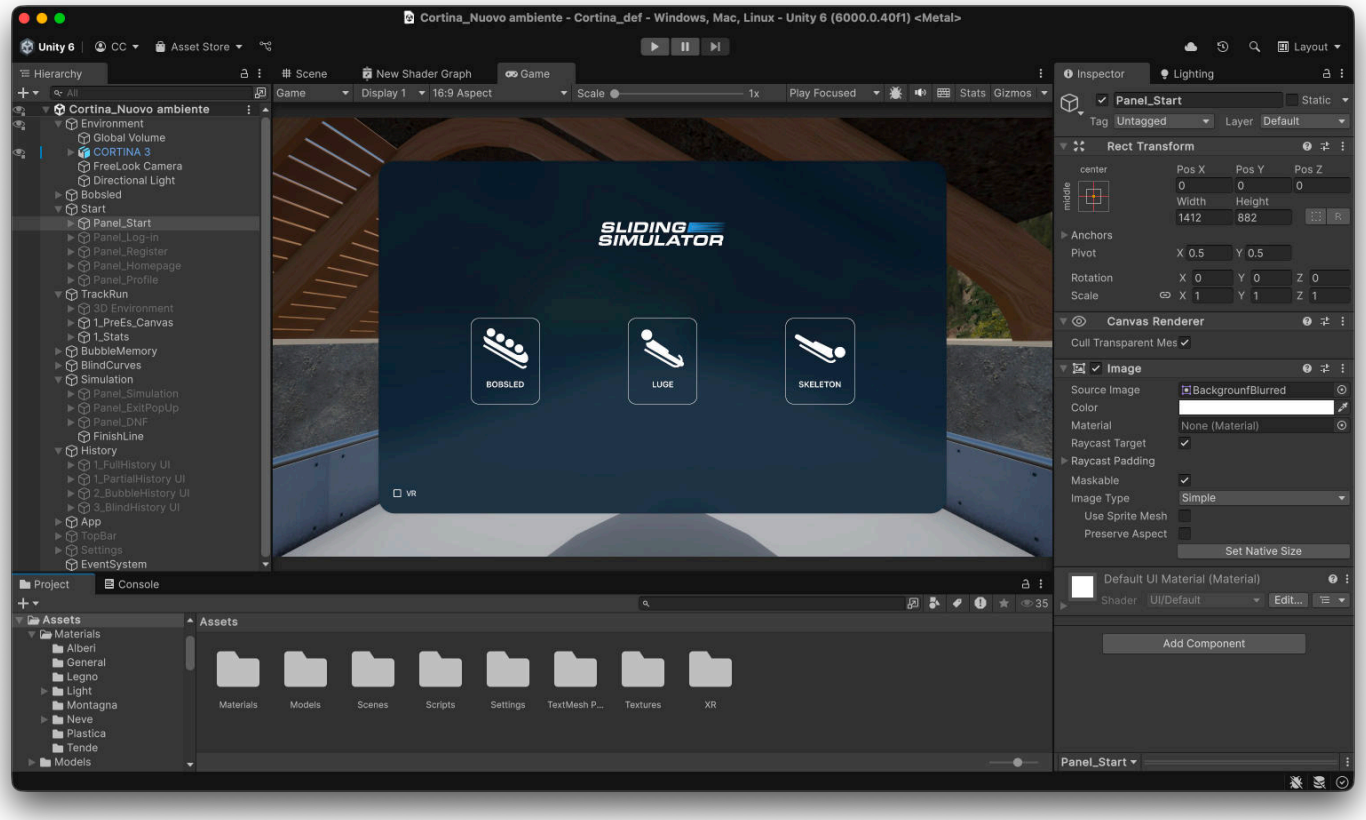


Fig.72: Explanatory screen of the Unity setup

This was determined through an analysis of real POV videos of actual descents, ensuring that the virtual perspective matches the experience of athletes on the track as closely as possible. A dedicated script also allows the camera position to be dynamically adjusted based on the user's physical parameters, enabling the simulator to provide each athlete with a personalised and realistic point of view.

Once the visual and spatial setup was complete, the scripting phase began. It is important to note that many of the scripts were initially developed with the support of artificial intelligence tools and will later be refined and validated by software engineers to ensure full functionality and optimised code.

The main idea behind the scene structure is that each panel has its own dedicated controller, as will be explained in the following sections. All scripts ending in 'Controller' are therefore either attached to the corresponding panel or to its preview elements. In contrast, the runtime and core scripts are linked to empty objects in the scene.

The scripts were created in C# and organised into eight categories, These categories are used to structure the following sections: Core, Service, Physics, UI, TrackRun, BubbleMemory, BlindCurves and History. Each script is introduced briefly, with an explanation of its main functionality and its relationship with other components.

6.2.1 Core (BootStrap, PanelId, PanelRouter, Session, SimulationSession)

This section contains the scripts that manage the system as a whole. These scripts define the game session, handle the UI panels and initiate the game.

BootStrap.cs acts as the initialisation script. Before displaying the interface, it verifies that all user data is accessible; if not, it generates it. The *UserDatabase.Instance.LoadOrCreate()* command guarantees that the users.json file exists and has been loaded into memory. *ui.Show(PanelId.Start)* then displays the StartPanel, while *OnBobsledPressed()* handles the transition from the Start panel to the Login panel.

PanelId.cs is an enum that lists the logical IDs of all the panels, this prevents string-based errors by providing a stable identifier for each panel. The *PanelRouter.cs* uses these IDs to activate the correct panel.

PanelRouter.cs acts as the 'director' of the UI panels.
Its main structure is a list of PanelId and GameObject pairs, linked through the Inspector. In the *Awake()* method, it creates a PanelId to GameObject map and disables all panels. The *Show(PanelId id)* method hides all panels except the requested one. *ShowError(string)* manages error messages, forwarding them to the *ErrorBanner.cs*.
This script ensures that only one panel is active at a time to avoid overlapping or 'ghost' screens.

The *Session.cs* script stores the current username after login and represents the global state of the logged-in user or guest.
SimulationSession.cs, on the other hand, stores the current simulation mode and the specific parameters for each exercise. It also offers reset and validate functions to restore sensible default values.
The setup panels configure these options, which are then read by the simulation managers to correctly initialise each exercise.

6.2.2 Service (BlindCurvesDTO, BubbleMemoryDTO, TrackRunDTO, UserProfile, JsonStorage, UserDatabase, UserFiles)

This category includes all the scripts responsible for saving and maintaining data persistence on disk.

It begins with DTOs (Data Transfer Objects), which define the data structures that the rest of the system reads and writes.
This category includes *BlindCurvesDTO.cs*, *BubbleMemoryDTO.cs*, *TrackRunDTO.cs* and *UserProfile.cs*.
JsonStorage.cs is a utility library for reading and writing JSON files.

UserDatabase.cs acts as an in-memory singleton that manages *users.json*.

It handles the loading or creation of the user database and provides read, edit and save access. The *LoadOrCreate()* method reads *users.json* if it exists or initialises an empty list and saves it to ensure the file is always present. The *Save()* method writes the current user state to disk, while the *UsernameExists(name)* method check for existing profiles. When a new profile is created, it is added to the list and saved.

Finally, *UserFiles.cs* manages all per-user files, such as *User_TrackRun.json, User_BlindCurves.json* and *User_BubbleMemory.json*, which store the user's simulation data. It defines where and how this data is saved, and provides methods to handle exercise-related files.

6.2.3 Physics (BobRunMonitor, BobsledPhysiscsController, FinishLineTrigger, WorldResetService)

These scripts control the bobsleigh capsule within the virtual environment. They control the sled's behaviour during the simulation and serve as a test model for the user interface.

BobRunMonitor.cs tracks time, measures speed and establishes whether a run ends successfully or in a crash. It handles the statistics displayed in the General Stats panel and forms the core of the end-of-run logic. A run is considered finished when the bobsleigh either reaches the end target or its velocity falls below a defined threshold.
The *SetPaused(true/false)* method pauses or resumes the internal progression; on crash or completion, it sets *rb.isKinematic = true* and resets all velocities.

BobsledPhysicsController.cs acts as the main controller for the bobsled's Rigidbody.

FinishLineTrigger.cs defines the physical finish line of the track.
When applied to a box collider configured as a trigger, it detects when the bobsled has reached the end of the course.

Finally, *WorldResetService.cs* manages the bobsleigh's reset when the simulation restarts or the run is completed. It repositions the sled to its initial state and clears temporary objects from the scene, ensuring a consistent and stable environment for each new session.

6.2.4 UI (CenteredGridLayout, ErrorBanner, GlobalTopBar, MinMaxSlider, MinMaxSliderHandle, LoginController, RegisterController, ProfileController, HomeController, SimulationCanvasController)

This section includes scripts for managing specific UI elements, such as the centred grid, error banners and dual-handle sliders, as well as controllers for the access, registration, homepage and simulation panels that do not belong to other categories.

As the name suggests, *CenteredGridLayout.cs* manages a centred grid of elements. This script was used in the preview of the Bubble Memory exercise and in the result input screen of the same exercise.

The *ErrorBanner.cs* file handles the fade-in and fade-out animations of error messages displayed in the UI, for example in cases of incorrect login credentials or invalid input. The *Show(msg)* method sets the message text and activates the banner, while the *Hide()* method clears the message and hides the component.

GlobalTopBar.cs manages the profile button (for logged-in users) and the exit button (for guests) of each panel.
It determines which panels each button should be visible on and controls which button appears based on the user's session type.

MinMaxSlider.cs and *MinMaxSliderHandle.cs* control the dual-handle slider used in the TrackRun setup screen. These files define how the slider moves and what values are displayed, thereby determining the start and finish points of the simulation.

The *LoginController.cs* file manages the logic of the login screen.
It receives the username input, checks for its existence in the database, starts the session for both registered users and guests, and navigates to the homepage.

RegisterController.cs handles the register screen. It creates new user profiles, validates input data, checks if usernames already exist and saves new users to *users.json* while creating their folder with the three empty exercise files. It then returns to the login screen.

ProfileController.cs is attached to the Profile panel and manages its internal buttons. It loads the current user's data, validates and saves any changes, updates the session in case of a username change and provides quick access to the logout function.

HomeController.cs manages the Home panel and directs the user to one of the three exercises, checking whether access was made via the login process or as a guest.

Finally, *SimulationCanvasController.cs* handles the HUD, the DNF overlay, data saving and navigation during the simulation. It listens to events from the *BobRunMonitor.cs* to update the time and speed in real time, save the results and display the statistics. The script also controls the three main buttons in the simulation panel: 'Restart', which calls the setup callback, resets the HUD and starts a new run; 'Pause/Play', which toggles physics freezing; and 'Exit', which stops the simulation,

opens the save confirmation pop-up and returns to the panel defined in *BeginSimulation(...)*. It also connects to the exercise DTOs to update their variables accordingly.

6.2.5 TrackRun (SetupController, SetupPreview, CurveIndexLocator, RuntimeController, StatsController)

This group includes all scripts related to the Track Run exercise, including both Full and Partial modes.

TrackRunSetupController.cs manages the configuration screen for the Track Run exercise. It enables users to select either a full run (entire track) or a partial run (selected range of curves), validates the input and prepares the simulation parameters.
The controller writes these parameters into the *SimulationSession.cs* and uses the *CurveIndexLocator.cs* to determine the spawn point that corresponds to the selected start curve.

The *TrackRunSetupPreview.cs* file is responsible for displaying the graphical preview of the track. It shows the segments from Start to Finish (Curve 1–14) and highlights the ones that are included in the selected range, depending on whether the Full or Partial option is chosen and the MinMaxSlider range. This is purely visual and does not interact with the simulation logic.

CurveIndexLocator.cs acts as a spatial map of the track. It exposes the transform references for the start of each curve and the final gate.
It also provides utility methods to retrieve either a curve's starting point or the gate that follows it. It is used to to determine the initial spawn position, and to define the virtual finish target for the *BobRunMonitor.cs*.

TrackRunRuntimeController.cs configures the runtime logic of the Track Run exercise. It determines where the run should end, either at the final gate for full runs or at the gate following the last selected curve for partial runs. It reads the necessary reference points from *CurveIndexLocator.cs* and sets up the *BobRunMonitor.cs* with the correct end target and stop conditions.

Finally, *TrackRunStatsController.cs* donfigures and displays the summary screen of the run.

6.2.6 BubbleMemory (SetupController, PreviewController, BubblePreviewItem, RuntimeController, BubbleStimulusView3D, ResultsController, BubbleResultSlot, StatsController)

This section covers all the scripts relating to the 'Bubble Memory' exercise, from the setup screen to the simulation phase, inputting the results, and the post-exercise statistics.

BubbleMemorySetupController.cs manages the Bubble Memory setup screen. It enables users to select the number of bubbles (1–14), switch between Number and Color modes (ensuring that at least one is always active), and initiate the simulation. When launched, it configures the simulation session and requests *BubbleMemoryRuntimeController.cs* to spawn the bubbles along the track.

BubblePreviewController.cs handles the interactive preview of the bubbles in the exercise setup panel. It controls the number of bubbles displayed and whether each bubble shows a number, a colour, or both. The preview updates dynamically whenever the user changes a toggle or the slider value.

BubblePreviewItem.cs represents each preview bubble in the UI. This is used by *BubblePreviewController.cs* to generate and update the list of preview bubbles.

BubbleMemoryRuntimeController.cs spawns N stimulus bubbles at predefined positions along the track (one per curve). Each bubble is assigned a number (1–9) and/or a colour. The script also builds the ordered ground truth sequence (*CurrentGroundTruth*) used later for answer verification.

BubbleStimulusView3D.cs is attached to the 3D bubble prefab in the scene. When the bubbles are spawned, it configures their visual properties: it enables or hides the 3D number and applies the selected colour to the material renderer.

BubbleMemoryResultsController.cs manages the entire post-run phase, during which the user inputs and verifies the remembered sequence. It activates a grid of up to 14 input slots, displays the corresponding keypads (numbers and/or colours) and supports undo and redo actions. It also compares the user's answers with the *GroundTruth* generated at runtime. After verification, the review interface is shown with correct and incorrect counts. The script also saves the records to disk.

BubbleResultSlot.cs defines the behaviour of each slot in the results screen. During input, it displays a placeholder and accepts user input. During the review stage, it highlights the correct or incorrect answers, displays the correct value when the user hovers over it and retains its state after reactivation.

Finally, *BubbleMemoryStatsController.cs* handles the statistics panel, displaying general performance data for a Bubble Memory run. It also enables the user to return to the 'Input Results' screen to review the previously verified state.

6.2.7 BlindCurves (SetupController, SetupPreview, BlockTrigger, RuntimeController, StatsController)

This group includes all the scripts related to the Blind Curves exercise. *BlindCurvesSetupController.cs*, *BlindCurvesSetupPreview.cs* and *BlindCurvesStatsController.cs* perform functions similar to those of the corresponding scripts in the other exercises.

BlindCurvesBlockTrigger.cs is attached to the box colliders that define the track segments where the screen should turn black. It acts as a section trigger, signalling when the bobsled enters or exits the volume of a blocked (or 'blind') curve.

Finally, *BlindCurvesRuntimeController.cs* manages the blackout effect during the exercise. It activates or deactivates a black overlay with a fade transition when the bobsleigh crosses the designated 'blind' curves. The script keeps track of which curves are obscured, counts the number of active triggers and controls the fade-in and fade-out of the blackout panel throughout the run.

6.2.8 History (TrackRunFullController, MonthCalendar, StatPoint, StatsToolTip, UILineStrip)

This category includes all scripts related to the 'Historical Statistics' section. As the 'Partial Track Run ',‘Bubble Memory' and 'Blind Curves' statistics screens have not yet been developed, the focus of this section is on the scripts used for the 'Full Track Run' statistics interface.

HistoryTrackRunFullController.cs builds and displays a historical graph showing full track runs over time (X-axis = date/time; Y-axis = run duration in seconds). It loads the user's run data and filters it to include only 'Full Runs'. It also has the option to include 'DNF' entries via a toggle. The script creates point prefabs inside the plot area, generates date labels along the X-axis and draws a line connecting the data points. It also manages hover and tooltip interactions.

StatPoint.cs is attached to each plotted point on the graph. Each point supports normal and hover states. When the user hovers over a point, its appearance changes (sprite or fill) and a pop-up is displayed showing the formatted run data (time, average speed and maximum speed). When the hover ends, the point restores its normal state and hides the pop-up.
StatsTooltip.cs manages the pop-up window that appears when the user hover over a *StatPoint*.

Finally, *UILineStrip.cs* defines a custom UI Graphic component that draws a thick polyline connecting the 2D points of the graph using triangles, visually linking the data in a smooth and continuous way.

6.3 VR AND SCREEN SIMULATION ADAPTATION

As discussed in *Chapter 1*, the simulator has been designed for use with the Hexalab configuration. This comprises a six-degrees-of-freedom motion platform and a curved screen positioned in front of the user for visualising the virtual environment. However, the sliding simulator is intended to be adaptable to multiple contexts and use cases. Accordingly, it must also be capable of operating with a head-mounted display (HMD). As this adaptation has not yet been implemented in practice, the discussion here remains theoretical. The focus is on the key differences between curved-screen CAVE systems and VR systems, as well as the necessary adjustments to the visual display to make the simulator usable and coherent in different contexts.

The different technologies impose distinct constraints and design implications. The curved-screen setup assumes a fixed viewing distance, consistent geometry, and a known physical environment.
Advantages include high resolution across a large display area and low latency, as active head tracking is not required. This produces a stable spatial reference that enhances motion precision and depth perception (Tcha-Tokey et al., 2017). Conversely, VR systems present challenges such as lower pixel density per degree of visual angle and potential visual discomfort. However, they provide stereoscopic vision and head tracking, which significantly increases spatial embodiment.

In CAVE-like environments and curved screen setups, the user's field of view is similar to that of the human eye (around 180°), whereas most HMDs still offer a narrower field of view. Furthermore, the sense of embodiment differs substantially: in the first case, users naturally perceive their own bodies within the environment; in VR, however, the absence of a visible body can affect proprioception and spatial awareness.
From a physiological perspective, CAVE and curved screen vision are natural. However, the decoupling of vergence and accommodation in HMDs can lead to visual strain or nausea (Philpot et al., 2017).
Studies of ergonomics and perception confirm that these differences affect the overall user experience. Auer et al. (2021) found that mental demand, physical effort, and perceived workload were significantly higher in VR conditions, primarily due to the weight of the headset and the complexity of interaction. Participants also reported higher levels of simulator sickness after VR exposure and generally preferred the curved-screen setup, citing comfort and visual stability as key reasons.

An interesting consideration emerges from user observations regarding the perception of space in the Philpot et al. (2017) study.

Some users noted the absence of a ceiling and rear wall when using the CAVE system, while others appreciated the freedom to look in any direction when using the HMD. This aspect is particularly relevant for the Sliding Simulator, which is designed to support also the training of luge athletes whose point of view is oriented upwards. In such cases, the VR configuration is more suitable since the Hexalab setup cannot reproduce the ceiling view due to its open structure.

Adapting the simulator to both configurations requires different visual calibration strategies. In the Hexalab system, rendering must be geometrically corrected for a concave surface based on the user's eye position to prevent distortion. This involves using an off-axis projection, similar to that employed in CAVE or powerwall systems, to ensure geometric accuracy and a stable focal plane. Maintaining a consistent viewing distance reduces visual fatigue, which is a crucial factor in fast-motion simulations such as bobsleigh.

In VR setups, the camera system must be reconfigured for head-tracked stereoscopic rendering, prioritising stable refresh rates. Controlling the field of view and peripheral contrast properly is essential to limiting motion sickness, particularly in high-speed contexts where rapid optic flow can challenge orientation and balance (Keshavarz et al., 2014).

Finally, the two systems differ in terms of flexibility and scope of application. The curved-screen setup offers exceptional visual stability and is ideal for extended training sessions, though it is fixed to a dedicated facility. VR, by contrast, is portable and scalable, enabling deployment in remote locations and reducing infrastructure costs.

In summary, both systems provide an immersive simulation experience, but specific design adaptations are required to maintain coherence, comfort and realism in each case.

Therefore, the simulator's visualisation layer must incorporate conditional rendering parameters and mode-specific optimisations to ensure the same level of effectiveness and immersion, whether operating in curved screen, CAVE-like or VR configurations.

7.

USABILITY TESTING

This chapter outlines the user testing process and the subsequent design enhancements. Ten qualitative tests on mid-fidelity wireframes helped to validate the interaction flow, usability and clarity.
Based on user feedback and SEQ ratings, several refinements were made, including clearer navigation, improved visualisation of statistics, and revised interface logic for the profile and buttons.
Overall, the tests confirmed the design's usability, while also highlighting areas where greater clarity and accessibility could be achieved across different user categories.

7.1 STRUCTURE AND METHODOLOGY OF USER TESTS

Prior to implementation, twenty qualitative user tests were conducted on high-fidelity wireframes to validate the system's interactions, flow and clarity. Informal in-person interviews were then used to collect feedback and refine the design iteratively. Each session lasted approximately 20 minutes. Participants represented a range of ages and levels of technological familiarity to ensure that the interaction was clear and accessible to all user categories. The test was divided into several phases:

Introduction
Each participant was read a short text explaining the project, its context and the test procedure. They were asked to imagine they were a bobsleigh coach accompanying their athlete to test the simulator.
They were also asked to think aloud throughout the process to provide additional insights.

User flows
Using a computer, participants were guided through three user flows developed in Figma, covering almost all of the interface's screens.
Each flow included multiple tasks.

- *User Flow 1* started from the Start screen, requiring the selection of the discipline, the creation of a new account, logging in and navigating between exercises on the Homepage.

- *User Flow 2* began on the homepage and involved setting up and completing the Bubble Memory exercise, including the simulation phase, the result input and recap screens.

- *User Flow 3* required accessing the Profile section and exploring the historical statistics screens.

On each screen, the user was asked to answer the following question: *"What does this interface communicate to you?"* This was done to identify which elements were clear and which were not.

Single Ease Question (SEQ): Post-task satisfaction
The SEQ is a post-task questionnaire designed to capture users' immediate impressions right after they have completed a task, while the experience is still fresh in their minds. At the end of each task, participants rated its ease of use on a 7-point scale ranging from 1 (very difficult) to 7 (very easy). This method helps to identify which interactions felt intuitive, and which caused confusion or required extra effort.

System Usability Scale (SUS): Post-test assessment of usability
The SUS (System Usability Scale) is a standardised questionnaire used to measure perceived usability. It provides a score ranging from 0 to 100, with higher scores indicating better usability. The SUS questionnaire consists of ten questions, or statements, which respondents answer using a five-point scale. Respondents indicate their level of agreement or disagreement with the statements (1 = strongly disagree to 5 = strongly agree). This test was only provided to the last ten users and the results were validated based on ten answers.

Throughout the tests, the author observed the participants directly and took notes on their difficulties and behaviours during the sessions. These tests were particularly useful for refining some of the screens of the proposed UI. These results are described in the next section.

7.2 RESULTS AND INSIGHTS

This section provides a detailed overview of the results collected during the user testing phase, as well as the subsequent modifications made to the interface design. The qualitative feedback gathered during the sessions offered valuable insights into the system's overall usability, clarity and intuitiveness, enabling a more refined, user-centred design.

Based on observations and Single Ease Question (SEQ) ratings, several areas for improvement were identified, ranging from navigation clarity to the visual hierarchy of key elements. Each adjustment aimed to enhance interaction fluidity, reduce cognitive load and make the interface more consistent across all screens.

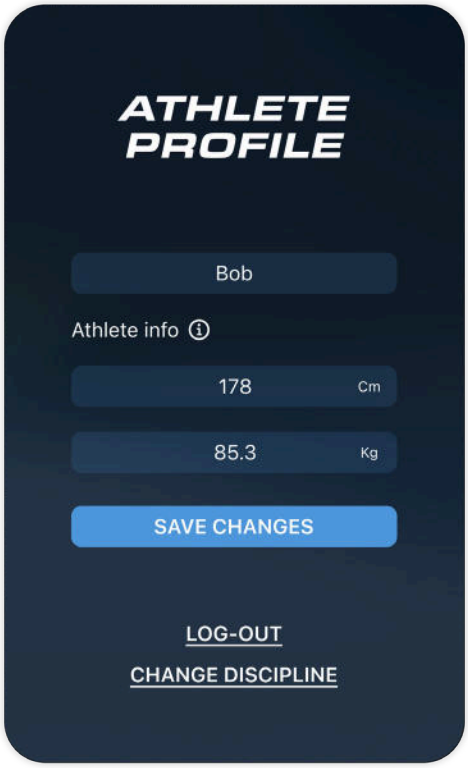
The following paragraphs outline the main changes implemented as a direct result of the testing process. These changes address both structural and visual refinements that improve the user experience and ensure the system is accessible to different types of users.
The most significant modifications are:

Profile screen
The settings have been moved from the Exercise screen to the Profile section, and the Change Discipline button has been removed.
The appearance and disappearance of error messages and positive feedback relating to data saving and profile updates have also been refined to ensure smoother, more consistent interactions (Fig. 74).

Exercises cards on the homepage
The cards initially consisted of a text block and an illustrative image of

Fig.73: Athlete profile changes, on the left the old version.

Fig.74: Athlete profile changes, on the right the new version.



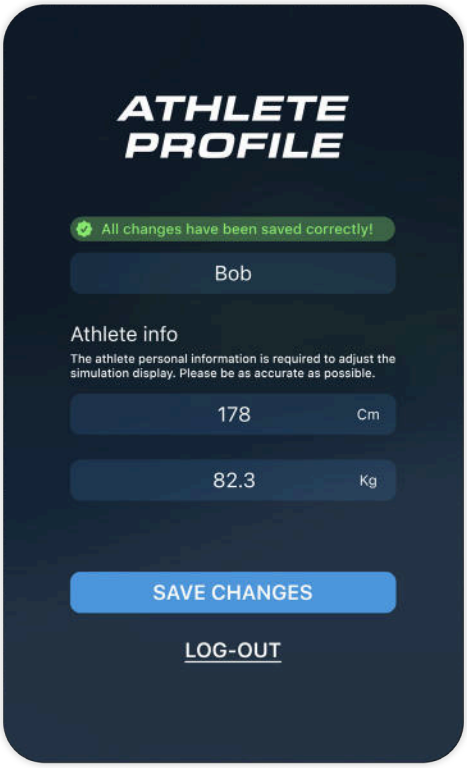
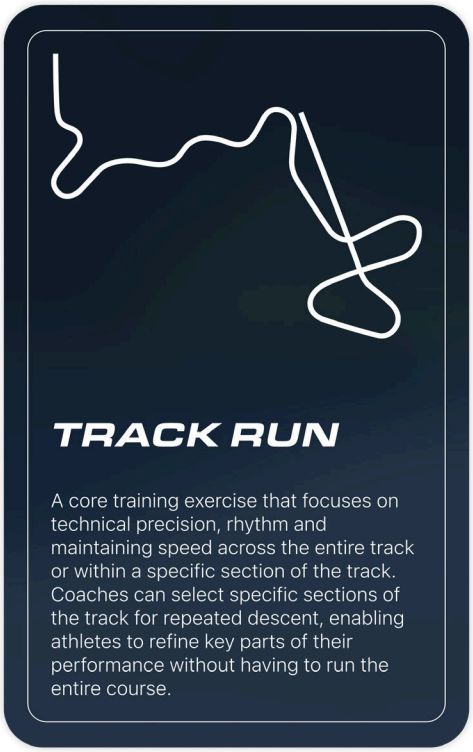


Fig.75: Exercise card changes, on the left the old version, on the right the new one.

Fig.76: Exercise card changes, on the right the new version.



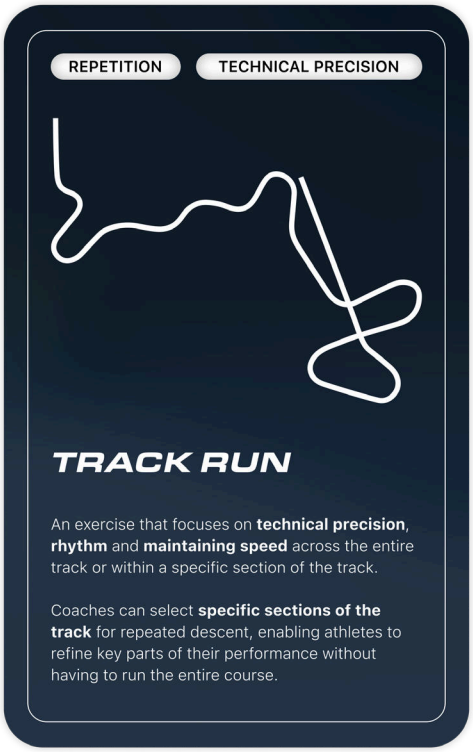


Fig.77: Bubble Memory input results navigation, the old version.

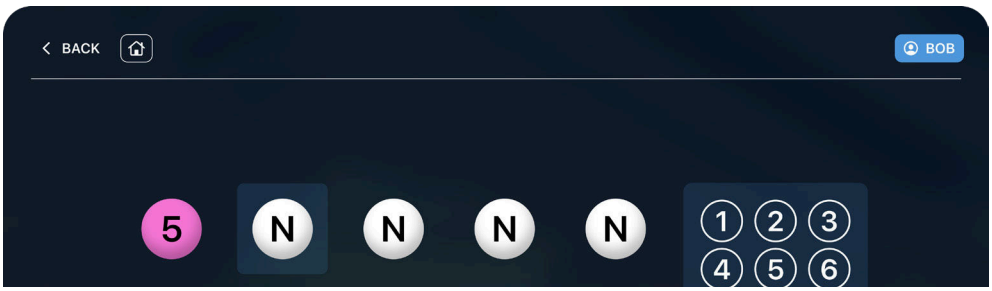
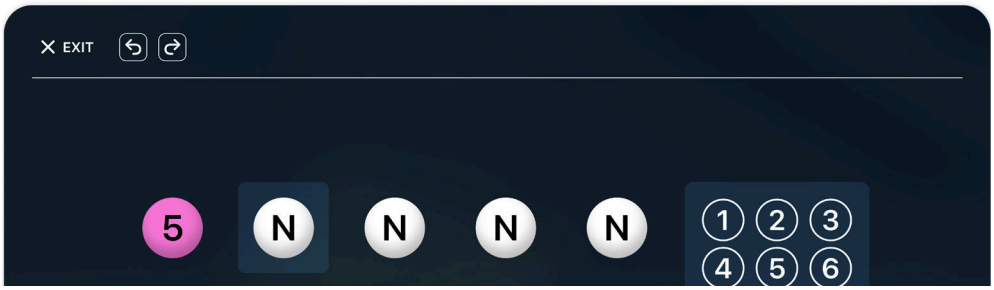


Fig.78: Bubble Memory input results navigation, the new version.



the exercise. Since this format was not sufficiently clear, keywords were later added to each card to better explain the training objectives, and portions of text were highlighted in bold to improve readability (Fig. 76).

Bubble memory input results navigation
Many users complained that they could not go back and forth across decisions on the Bubble Memory input results screen.
This issue has been addressed by introducing undo and redo functionalities, which make it easier for users to correct or modify their entries during the task (Fig. 78).

Exercise Summary screen
To make the post-exercise review even clearer, the final screen was divided into two sections: one displaying the completed track along with the exercise details (such as date, time, and athlete's name), and another showing the performance statistics previously included (Fig. 80).

Track run statistic screen
Another major difficulty was understanding the track run statistics page. At first, it displayed both partial and full runs on a single screen, which was confusing because the information from the two columns was mixed. Thanks to user feedback, it has been divided into two different layouts to improve clarity and readability. A DNF toggle has also been introduced on all statistics screens, enabling users to include or exclude unfinished runs from their data visualisations (Fig. 82 & Fig. 83).

Profile/Exit button
The logic behind the profile button has also been revised.

Fig.79: Blind Curves exercise review, the old version



Fig.80: Blind Curves exercise review, the new version



Whereas it previously appeared on every screen, it now only appears on the homepage and in the exercise and statistics sections, providing a cleaner and more focused navigation experience. An exit button has also been introduced that appears only when a guest user has logged in, allowing them to return to the start page.

Labelling
Several button labels and textual elements were adjusted to improve comprehension and communication across languages and user groups.

Info buttons
Finally, the info buttons were removed from the Registration and Profile

Fig.81: Track Run Statistics, the old version

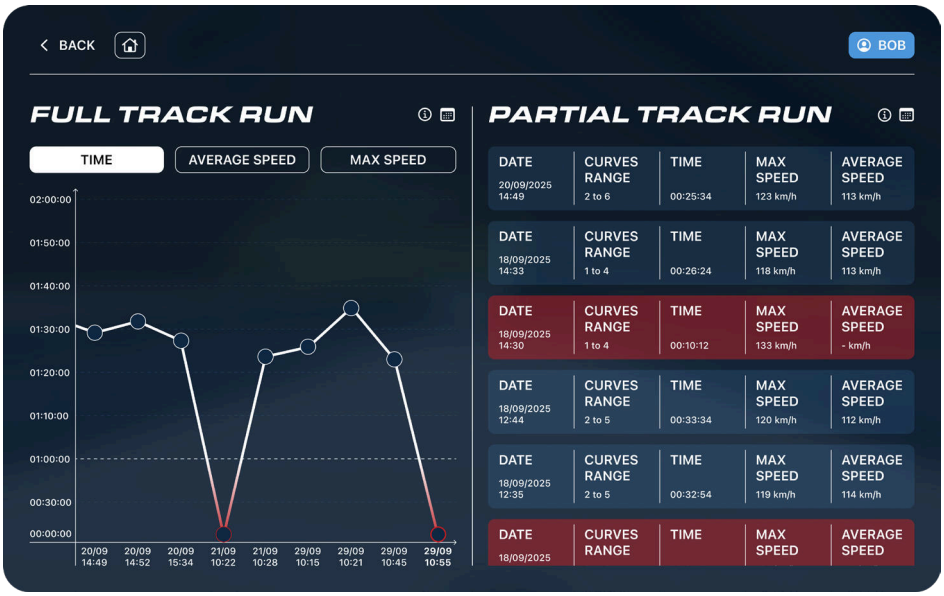


Fig.82: Track Run Statistics, the new version. Full track run layout

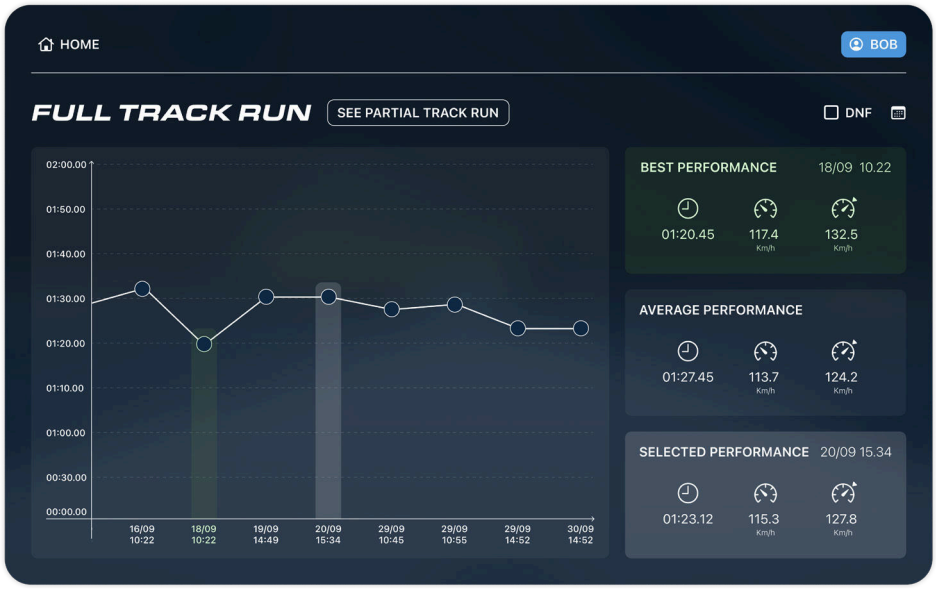


Fig.83: Track Run Statistics, the new version. Partial track run layout



screens and replaced with explicit, always-visible explanations to make interactions more intuitive. Conversely, new info buttons were added to the statistics graphs to provide concise, contextual descriptions to help users interpret their performance data more effectively.

Overall, participants understood the exercise setup screens (SEQ: 6.4) and the exercise result recap screens (SEQ: 6.8) well.
The Bubble Memory error summary screens were slightly less clear (SEQ: 5.7), primarily because of the hover interaction used to reveal extra information. However, this issue is expected to diminish as users become more familiar with the system. If necessary, an affordance could be introduced to prompt users to hover during their first interactions to improve discoverability. A similar consideration applies to the statistics screens, particularly the Bubble Memory one (SEQ: 5.8), which initially caused confusion when interpreting the graph. To address this, an info button was added to provide a brief explanation of the data visualisation and support user understanding.

The SUS (System Usability Scale) test also confirmed the positive feedback from participants: the score is around 89, which is considered excellent and demonstrates that the system is highly usable and well-received.

Although these user tests were essential to demonstrate and ensure the overall usability of the system, it would be particularly valuable to conduct further testing with professional athletes and industry experts. Their insights could provide more specific and technically informed feedback, especially regarding the statistics section and its relevance to real training analysis.

8.

CONCLUSIONS

This chapter outlines the main achievements and future directions of the project. It summarises the design and development of a dynamic simulator for sliding sports that integrates physical realism with cognitive training in order to improve athletes' perception and decision-making abilities. The conclusions emphasise the innovative dual-interface structure of the simulator and the potential of interaction design to bridge the gap between technology, perception and athletic performance. Proposed future developments include improving environmental fidelity through 3D scanning, expanding to other disciplines, integrating adaptive AI systems and refining multisensory cognitive tasks.

8.1 FUTURE DEVELOPMENTS

Future developments to the simulator could address several complementary aspects aimed at improving fidelity, adaptability and the overall quality of the training experience.

One significant improvement would be creating a digital track using high-precision 3D scanning and specialised modelling software.
This technology would enable highly accurate spatial data to be collected, capturing the geometry of the track, the thickness of the ice, and the position and dimensions of surrounding elements. This level of precision would provide a more realistic and immersive experience for users, as the shape, position and inclination of each curve are crucial for analysing and training the optimal trajectory.

As the Cortina Sliding Centre is not yet complete, the current environment is based on architectural plans and the official guidelines of the International Bobsleigh Sports Federation. Once the facility is complete, future access to real visual references, lighting conditions and environmental data would allow for far more accurate reconstruction of materials, textures and spatial proportions, significantly improving perceptual realism and training relevance. Furthermore, adapting the surrounding landscape and lighting to reflect the season associated with each ice condition would make the simulation contextually coherent, deepening immersion and sensory consistency.

Another development involves modelling and adapting the environment and physics for multiple tracks and different sliding disciplines, such as luge and skeleton. The process developed so far could easily be extended to new environments. However, this extension would require additional research into the specific body positions, points of view and perceptual references characteristic of each discipline, in order to ensure that the experience accurately reflects the sensations experienced by athletes during real descents.

To validate and refine these improvements, specific testing on motion sickness and discipline-based usability should be conducted.
Motion sickness studies would enable the visual flow, acceleration profiles and latency parameters to be fine-tuned, thus guaranteeing a safe and comfortable experience, even during extended training sessions. Meanwhile, usability evaluations with professional athletes, particularly those training at the new Cortina Sliding Centre, would provide valuable feedback on perceptual realism, performance parameters and visual cues along the track. This would strengthen the simulator's credibility as a professional training tool.

In parallel, integrating advanced cognitive tasks is another promising direction. While the cognitive exercises developed thus far are tailored to bobsleigh pilots, extending the simulator to other disciplines requires adapting these tasks to align with the cognitive and motor characteristics of each sport. Future research could explore dual-task models involving additional sensory modalities, such as hearing or touch.
This would transform cognitive tasks from 'additional stimuli' into a more integrated sensory training approach that reflects the cognitive complexity of high-performance sports. Furthermore, these exercises could be diversified to suit a broader range of users, from professional athletes to beginners and the general public, opening up the simulator to educational and outreach contexts.

Finally, integrating artificial intelligence and adaptive systems could transform the simulator into an intelligent training environment.
Through reinforcement learning and predictive modelling, the system could monitor physiological parameters such as heart rate, pupil dilation or reaction time and automatically adjust task difficulty in real time.
AI could anticipate declines in attention or physical performance, suggesting recovery exercises or alternative tasks, or identifying 'flow states' and extending them by dynamically adapting the training rhythm.
As these technologies evolve, particular attention must be given to the ethical use of biometric and behavioural data to ensure transparency and privacy and to promote the responsible application of AI-driven systems within sports training environments.

8.2 CONCLUSIONS

This thesis presents a project that explored the design and development of a dynamic simulator for sliding sports. The simulator was designed to support the training and performance analysis of professional bobsleigh, skeleton and luge athletes in preparation for the 2026 Milano–Cortina Winter Olympics.

Situated at the intersection of interaction design, cognitive training and virtual simulation, the research addressed how digital environments can reproduce the perceptual and decision-making demands of high-speed disciplines. Within this framework, the work built upon the most advanced examples of sports simulators while introducing an additional layer of cognitive engagement largely absent from comparable systems.

A state-of-the-art analysis revealed that sliding simulators have progressively evolved from static visual familiarisation tools to fully immersive systems.

However, despite remarkable technological advances, existing simulators still mainly focus on physical realism and rarely include the cognitive dimension of training. This project directly addressed this gap by integrating dual-task and cognitive exercises designed to train athletes' visualisation, anticipation, and reaction abilities, mental skills that are as important as physical strength in determining performance.

The thesis documented the entire design process, from defining training needs and establishing theoretical foundations, to constructing the virtual environment and interface system. The Cortina Sliding Centre was modelled in Blender and then refined in Unity. This process enabled the creation of an immersive and realistic environment that could reproduce the perceptual conditions of a real descent.

The interface and interaction design played a crucial mediating role between the physical simulation and the cognitive dimension of the experience. Based on user research and the definition of three personas, the simulator was designed as a dual-interface system comprising an immersive interface for athletes and a management interface for coaches and researchers. This structure ensured clarity, accessibility, and efficient control across different user roles.

Implementing the simulator in Unity was a central technical milestone. The simulator operates entirely within a single scene, optimising performance and ensuring seamless transitions between exercises.

User testing confirmed the interface's clarity, coherence and usability, validating its capacity to accommodate users with different levels of expertise. Feedback collected through qualitative sessions informed targeted refinements that improved navigation, feedback clarity, and the logic of statistics visualisation. These results confirmed the system's potential as an accessible and intuitive training platform.

From a conceptual standpoint, the project successfully combined realistic simulation and cognitive interaction to create a unified ecosystem in which perception, decision-making and motor control coexist.
Unlike the simulators analysed in the literature, which generally aim to reproduce physical motion with increasing accuracy, this work emphasises learning through perception. This approach aligns with contemporary perspectives in sports science and interaction design, which regard cognitive adaptation as integral to athletic performance.

In summary, the project has demonstrated that it is possible to design a simulation system that replicates physical dynamics and trains mental readiness and perceptual awareness.
By merging UX/UI design, cognitive theory and virtual simulation, this

thesis has contributed to a more holistic and human-centred understanding of sports technology.

While the version presented here represents the first complete development phase, the results already show consistency with the initial objectives. The simulator faithfully reproduces the visual and spatial qualities of real sliding environments, and its modular design allows it to be adapted for future updates and other disciplines. Further testing with professional athletes and technical staff will provide the empirical basis for optimising motion fidelity, physiological comfort, and training effectiveness.

Ultimately, this work confirms the central role of interaction design in the evolution of sports simulation systems, not merely as an interface layer, but as a strategic component connecting technology, perception, and human performance.

Artificial intelligence tools were used throughout the development of this thesis to assist the written content. Specifically, AI-based language models were used to refine and enhance the grammar, translation and academic tone of the written text. Additionally, AI-assisted code generation tools were employed during the Unity implementation phase, and all code was subsequently reviewed, refined, and adapted by the author. All AI-generated content was critically evaluated and adjusted to preserve conceptual accuracy, originality and authorial intent.

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