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Virtual Reality for the Preservation and Promotion of Historical Real Tennis^{*}

Ronan Gagne¹[0000-0002-4762-4342], Sony Saint-Auret²[1111-2222-3333-4444],
Pierre Duc-Martin³, and Valérie Gouranton³[0000-0002-9351-2747]

¹ Univ Rennes, Inria, CNRS, IRISA, Rennes, France

² Inria, CNRS, IRISA, Rennes, France

³ Univ Rennes, INSA Rennes, Inria, CNRS, IRISA, Rennes, France

Abstract. Real tennis or “courte paume” in its original naming in French, is a racket sport that has been played for centuries and is considered the ancestor of tennis. It was a very popular sport in Europe during the Renaissance period, practiced in every layer of the society. It is still practiced today in few courts in the world, especially in United Kingdom, France, Australia, and USA. It has been listed in the Inventory of Intangible Cultural Heritage in France since 2012. The goal of our project is to elicit interest in this historical sport and for the new and future generations to experience it. We developed a virtual environment that enables its users to experience real tennis game. This environment was then tested to assess its acceptability and usability in different context of use. We found that such use of virtual reality enabled our participants to discover the history and rules of this sport, in a didactic and pleasant manner. We hope that our VR application will encourage younger and future generations to play real tennis.

Keywords: Digital Cultural Heritage · Virtual reality · Intangible Heritage · Sport Heritage

1 Introduction

Traditional sports are considered intangible cultural heritage (ICH) because they represent the cultural expressions and practices of a particular community. Intangible cultural heritage is defined by UNESCO as “the practices, representations, expressions, knowledge, skills – as well as the instruments, objects, artifacts and cultural spaces associated therewith – that communities, groups and, in some cases, individuals recognize as part of their cultural heritage” [24].

Traditional sports are deeply rooted in the culture and history of a particular community or region. These sports are an essential part of intangible cultural heritage and have been often passed down through generations as oral traditions, with many of the rules and techniques of these sports being learned through practice and experience rather than through written instruction [6].

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The preservation of traditional sports as intangible heritage is essential because it helps to maintain cultural diversity and promote understanding between different communities. Traditional sports can also have economic benefits, with many communities using them as a means of attracting tourism and generating revenue. By preserving traditional sports, we can ensure that these cultural expressions are passed down to future generations and continue to contribute to the cultural heritage of the world.

However, preserving traditional sports can be challenging, especially when they are not widely practiced or are in danger of being lost due to social or economic changes. Lim *et al.* [11], emphasise the importance of preserving traditional human activities and point out that advances in the production and 3D animation of virtual humans support the growth of interactive simulations and experiences of these activities.

In this work, we present the design and an evaluation of a Virtual Reality (VR) application dedicated to the preservation and promotion of a European traditional sport, real tennis.

2 Related works

2.1 Real Tennis

Real tennis, considered as the ancestor of racket sports such as tennis, squash or Basque pelota, has an important historical interest in European culture [14, 3].

Real tennis was played since the 15th c. in dedicated buildings, either in aristocratic estates or in city centers. After the decline of real tennis in 18th c., these buildings were destroyed or modified and reallocated to other uses. It is not uncommon to find foundations of real tennis buildings during archaeological excavations in the cities, and their characteristic dimensions, 10 meters wide and 30 meters long, facilitate their identification.

It was practiced in every layer of the society, by women as well as by men, and it was not uncommon to attend mixed matches. It is particularly studied in France [7], as it has left important traces in French culture, many linguistic expressions still used today are coming from this sport. Real tennis is still played, mainly in UK, the USA, France, and Australia, with international competitions, but the number of players is small because of the limited number of courts. There is a will to develop this sport, with the construction of several new courts in the world, as in Sidney and Amsterdam, and the restoration of old courts that were no longer used to play, as the court of Chinon in France. The game is played inside a covered court separated into two parts by a net, the Service side and the Hazard side. The court is surrounded by two (*Quarre* court) or three penthouses (*Dedans* court), covered by a sloping roof (Fig. 1). The openings in the penthouses can vary a little from one court to another.

2.2 The Use of Virtual Reality for Cultural Heritage Preservation

Virtual reality (VR) and more generally extended realities (XR), are now widely used in the domain of cultural heritage as they provide the means of document-

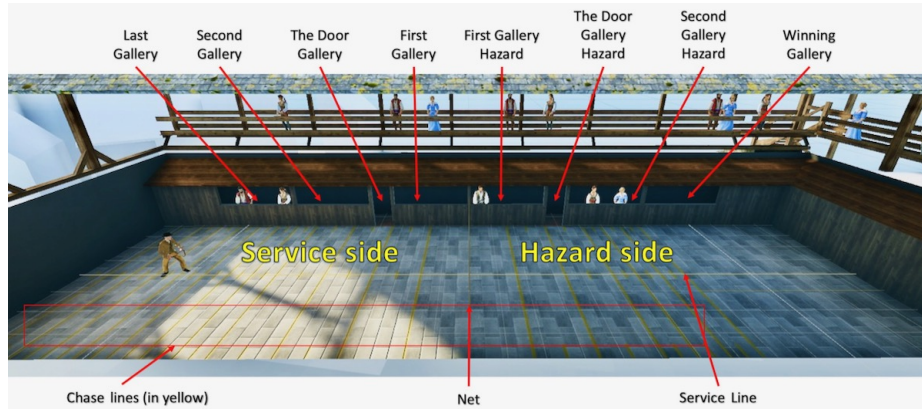


Fig. 1. Overview of a real tennis court (Quarre court)

ing, recovering and presenting historical contexts [2]. Beyond historical material such as artefacts, buildings, monuments, or cities, XR also allows to represent intangible cultural heritage with many different human activities such as crafting [16], artistic expression, [1, 20, 4], or traditional sports [23].

Skublewska-Paszowska *et al.* [21] conducted a systematic review of the literature to identify relevant studies related to 3D technologies and intangible cultural heritage preservation. They specifically review two studies related to sport, [10, 12]. Both focus on the extraction and reproduction of 3D sports movements, from 2D images. The 3D animations provided in these two works can be used to animate human characters in immersive simulations. This approach is developed further in the work of Tisserand *et al.*, [23], which proposes a framework for the preservation of traditional sports through gamification, applied to traditional Gaelic sport and Basque pelota, based on low cost motion capture to train users to perform correct movements. In the same idea, Lo *et al.*, [13] used VR to create a virtual exhibition showcasing traditional Chinese martial arts. The exhibition allowed visitors to engage with the martial arts through interactive simulations, such as practicing martial arts moves with a virtual instructor. This kind of approach is also widely used for the preservation of traditional and folkloric dances [15, 1, 17].

Beyond movement, traditional sports activities also rely on other features, such as cultural contexts and game rules. These aspects are important to preserve, and virtual reality offers an interesting medium for both. As an example, Selmanović *et al.*, [18] explored the use of VR to propose experiencing traditional bridge diving at Stari Most, the old bridge in the historic city of Mostar in Bosnia and Herzegovina, a UNESCO World Heritage Site. The experience is enhanced by narrative elements that present the cultural context, with the associated festival, as well as the history of the bridge. In the same vein, the article by [26] proposes a visit to the archaeological site of Olympia in augmented reality during which visitors can observe reconstitutions of sporting events from Antiq-

uity. While the two previous studies did not take into account sports rules, the work of Setiawan *et al.*, [19], in contrast, focuses on the implementation of the rules of the traditional Indonesian game Benthik in VR, but without representation of the cultural context. The virtual environment is completely abstract, the objective being to propose a motivating and fun environment for an initiation to Benthik.

With different but complementary approaches, these works aim to propose solutions to preserve traditional sports. These different approaches thus highlight the complexity of traditional sports preservation as intangible cultural heritage. In this work, we want to address the human activity involved in a traditional sports, its cultural context, the associated rules, and the specific movements.

3 Method

The work presented in this paper is an extension of the methodological paper [9] that studies the representation of sport heritage in VR, with a focus on Real Tennis. In this previous paper, we propose a model to identify the main elements to consider in order to propose a virtual environment (VE) through different perspectives.

We can identify three different and complementary goals for a traditional sport reconstruction.

- Propose a realistic practice of the sport, with a focus on faithful reproduction of the movements.
- Preserve the traditional and popular culture associated with the sport. In this perspective, the sport must be considered in a more general and cultural context. VR applications can support such aim, through a sensory representation (graphic, sound...), associated to narrative scenarios.
- Disseminate and promote traditional sports. The aim, here, is to give the possibility to a large public to discover and be initiated to traditional sports.

In this new work, we address the second and third objectives through an immersive experience comprising a presentation of real tennis' cultural context based on a structured scenario, with a playful tutorial to introduce the basics and rules of the game. Furthermore, we present the results of a user study we conducted to evaluate the presence, acceptability and usability of the VE.

3.1 Design and implementation

The VE presented in [9] proposes (i) a representation of the cultural and historical heritage associated to this traditional sport, (ii) an implementation of the rules and flows of the sport, and (iii) natural interactions for realistic sensations of real tennis.

In order to implement a didactic interactive scenario to guide the user in the discovery of real tennis, we integrated the scenario engine Xareus for Unity (based on [8]), available under licence at <https://xareus.insa-rennes.fr/>. It is

a scripting engine, based on Petri nets constituted of places, transitions and arcs. Tokens can be found in the places, and evolve from place to place through transitions. A transition can host a sensor and/or an effector that carry the relationship between a scenario and the VE. A sensor allows to observe elements of the scene, and blocks the transition as long as its condition is not validated. An effector allows to act on the scene when the transition is crossed by a token. A graphical representation is presented in Fig. 2, Left. Xareus integrates a graphical window in the Unity editor that allows to create, edit and follow the scenario.

The advantage of using such a scenario engine is to establish a clear framework to design and implement a didactic tutorial in VR that can evolve easily according to users feedback without coding effort. The complete didactic scenario is structured in two parts. First, a technical tutorial presents the basic concepts of the sport, and invites the user to practice two different actions in the game, a serve and a chase (Fig. 2, Right). The second part gives the user the possibility to visit the building with a presentation of the different parts of the court and the cultural aspects of the sport, to practice a full match against the virtual player, or to leave the experience.

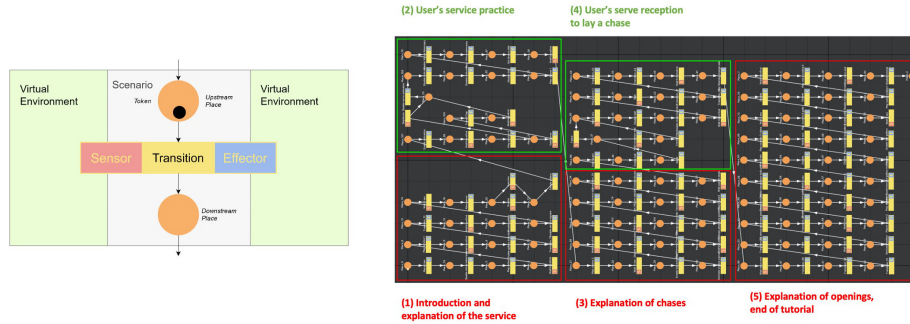


Fig. 2. Left : Petri net extended with event model. Right: Tutorial scenario.

User perspective of the didactic scenario From the user’s point of view, he or she is first orally introduced to the terrain and the service rule, using visual methaphors that highlight the targets (Fig. 3). The user is then invited to practice. The scenario enters the loop described above, which exits only after one successful serve, or after 10 failed attempts. In order to perform the service, the user has one raquette in one hand and the ball in the other hand. He or she must grasp the ball by pulling the trigger of the controller, and throws it by launching the ball and releasing the trigger in a synchronised gesture, as in a real service. Then, the basic of chase rule is explained and the player changes side. He has to receive a serve from the virtual opponent, and return it on the other side, to mark a chase. This phase is also in a 10 tries loop and exit at the



Fig. 3. Top, Left: Service training, Right: Chase Training, Bottom, Left: Guided visit, Right: Score display.

first success. The chase area to win is highlighted on the court. At the end of this tutorial phase, a visit of the site is proposed, with teleportation to explanation panels, and the visitor has also the possibility to play a complete match.

3.2 Experimental protocol

We conducted a user study focusing on the evaluations of presence, acceptance and usability of the didactic scenario. We based the presence evaluation on the standard Slater-Usoh-Steed (SUS) questionnaire [22] consisting of 6 questions evaluated with a 7-point Likert scale, 1 meaning “Not at all”, 7 meaning “Completely” (Fig. 4, top, left). For the acceptance and usability evaluation, we used the extension of the standard unified theory of acceptance and use of technology UTAUT2 questionnaire proposed by Venkatesh *et al.* in [25]. It contains 9 questions, with at least one question per category of the model: performance expectation, effort expectation, social influence, facilitating conditions, hedonic motivation, perceived pleasure and habits (Fig. 4, top right). These questions are inspired and adapted from those proposed by [5]. Finally, the questionnaire also integrates more general questions about the user and his/her experience, listed in Fig. 4, bottom, as well as a free response section. For this study, we used an Oculus Quest 2, in stand-alone mode, in a large room to define a physical space of 10m x 10m to allow real movement.

Id	Question	Id	Question	Id	Question
P1	Please rate your sense of being in the virtual environment.	U1	I think this virtual environment allows me to learn faster than traditional methods.	G1	I think this virtual environment is useful for heritage conservation.
P2	To what extent were there times during the experience when the virtual environment was the reality for you?	U2	I think this virtual environment is easy to use.	G2	I think this virtual environment is useful for sport promotion.
P3	When you think back to the experience, do you think of virtual environment more as images that you saw or more as somewhere that you visited?	U3	I think people around me would like to use this virtual environment to discover a new sport.	G3	I think this virtual environment is useful for sport training.
P4	During the time of the experience, which was the strongest on the whole, your sense of being in the real room or of being in the virtual room?	U4	I think people around me would like to use this virtual environment to practice a sport regularly.	G4	I learnt new things (rules, history...) on real tennis.
P5	Consider your memory of being in the virtual room. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.	U5	This virtual environment seems to me to be complementary with traditional learning methods.	G5	I would like to discover more about the real tennis.
		U6	The use of this virtual environment is fun.	G6	I felt discomfort during the experiment. (7= no discomfort).
		U7	I enjoyed learning in this virtual environment.	G7	Overall evaluation of your experience.
		U8	I am ready to use this virtual environment again for a new session.		
		U9	If I have the opportunity, I will recommend the use of this virtual environment to my friends and family.		
P6	During the time of your experience, did you often think to yourself that you were actually in the real room?				

Fig. 4. Top, Left: Presence questionnaire, Right: Acceptability and Usability questionnaire, Bottom : General questionnaire.

The experimentations were conducted in two phases. In the first phase, XP1, the experiments involved a panel of 10 participants (4 men, 6 women) and took place in the historical Court building represented in the VR application (Fig. 5, left). In the second phase, XP2, the experiments involved a panel of 18 participants (14 men, 4 women) and took place in a gymnasium (Fig. 5, right).

One of the objectives of this two-phase study was to determine whether the location used for the VR experience had an impact on the usability and acceptability reported by the users. Indeed, it is questionable whether the VR application can be used as effectively in a real-world environment unrelated to the cultural heritage context being promoted.

It is important to note that the participant populations were very different between the two phases. In the XP1 phase, the population was mainly made up of inhabitants of the city centre district, with a fairly high average age ($m = 55.4$, $\sigma = 14.9$). The XP2 phase was conducted in a gymnasium located on the campus of the University of Science of the city. The population was made up of students with a younger average age ($m = 22.1$, $\sigma = 3.5$).

For the XP1 phase, the VR room was co-located with the real room. The participants therefore had the initial striking effect when they put on the headset of having a change of atmosphere without a change of physical location, and they could physically touch the boundaries of the court in VR, in the 10mx10m space. The user experience started with the tutorial presented in section 3.1. Once the scenario was completed, participants were able to visit the historical site or play a match. After the experience, they were invited to fill the questionnaire.

4 Results

4.1 Presence, usability and acceptability analysis

The mean results of the questionnaires are presented in Fig. 6. From these questionnaires, three main score variables were computed, Presence, Acceptability and two arbitrary constructs named PROM and TRAIN:



Fig. 5. User study in (left) the original building, and (right) a modern gymnasium.

Question	XP1 (m,σ)	XP2 (m,σ)	Total (m,σ)	Question	XP1 (m,σ)	XP2 (m,σ)	Total (m,σ)	Question	XP1 (m,σ)	XP2 (m,σ)	Total (m,σ)
P1	6.56, 0.73	6.11, 0.76	6.26, 0.76	U1	4.89, 2.09	4.5, 1.65	4.63, 1.78	G1	6.78, 0.67	6.33, 0.97	6.48, 0.89
P2	5.44, 1.51	5.06, 1.35	5.19, 1.39	U2	3.22, 2.33	4.72, 1.78	4.22, 2.06	G2	6.44, 1.13	5.67, 1.28	5.93, 1.27
P3	4.78, 2.17	5.28, 1.27	5.11, 1.6	U3	6, 1.22	5.94, 1.11	5.96, 1.13	G3	5.22, 1.99	3.61, 1.58	4.15, 1.85
P4	5.11, 2.03	5.17, 1.04	5.15, 1.41	U4	4.44, 2.19	2.83, 1.34	3.37, 1.8	G4	6.44, 1.13	6.33, 0.84	6.37, 0.93
P5	4.44, 1.51	5.11, 1.32	4.89, 1.4	U5	6, 1.12	5.67, 1.33	5.78, 1.25	G5	6.44, 0.73	5.72, 1.07	5.96, 1.02
P6	4.44, 2.3	4.06, 1.66	4.19, 1.86	U6	6.56, 0.53	6.5, 0.71	6.52, 0.64	G6	5.67, 2.06	5.28, 1.49	5.41, 1.67
				U7	6.22, 1.3	6.33, 0.77	6.3, 0.95	G7	6.33, 1	6, 0.97	6.11, 0.97
				U8	6.11, 1.36	6.33, 1.03	6.26, 1.13				
				U9	6.11, 1.96	6.44, 0.86	6.33, 1.3				

Fig. 6. Left: SUS results, Center: UTAUT2 results, Right : General results

Firstly, based on the SUS questionnaire's items, participants reported a mean score of Presence of 5.07 ± 0.75 for the whole population, 5.11 ± 0.55 for the XP2's group and 4.98 ± 1.08 for the XP1's group.

Then, based on the UTAUT2 questionnaire's items, participants reported a mean score of Acceptance of 5.49 ± 0.82 for the whole population, 5.48 ± 0.55 for the XP2's group and 5.51 ± 1.23 for the XP1's groups.

In order to assess the impact of our system on real tennis preservation and promotion, we consider the construct, PROM, based on the questions (U3, U5, U6, U7, U8, U9, G1, G2, G4, G5). In addition, in order to get feedback on sport training aspect from users, we consider a second construct, TRAIN, based on questions (U4,G3). The PROM construct presents a mean score of 6.19 ± 0.64 for the whole population, a mean score of 6.13 ± 0.51 for XP2's participants, and 6.31 ± 0.88 for XP1's participants. The TRAIN construct shows a total mean score of 3.76 ± 1.63 , XP2 is 3.22 ± 1.19 , and XP1 is 4.83 ± 1.92 .

4.2 Impact of the experiment location on questionnaire answers

We then compared the results obtained in our two groups. Most of our data didn't follow a normal distribution. Thus, Wilcoxon signed rank test was used to compare answers between XP2's participants and XP1's participants. Answers

tend to be high with no statistically significant difference between the two groups, except for questions **U4** ($p = 0.041$) and **G3** ($p = 0.033$) where participants from XP2 provided lower scores in general compared to XP1's participants.

4.3 Impact of Location on Presence, Acceptance and PROM Scores

To measure the impact of the experimentation location on the different scores, we ran a statistical analysis with location as a factor, and the presence, acceptance and PROM scores as dependent variables.

Homoscedasticity was rejected for presence ($p = 0.011$), and normality was rejected for PROM ($p = 0.003$). As such, Kruskal-Wallis was used for these constructs. No significant result was found (presence: $\chi^2 = 0.003$, $p = 0.959$, $df = 1$, $p_{wilcox} = 0.979$; PROM: $\chi^2 = 2.57$, $p = 0.109$, $df = 1$, $p_{wilcox} = 0.115$). As for acceptance, normality and homoscedasticity assumptions were not rejected ($p = 0.0686$ and $p = 0.116$ respectively), so an ANOVA was performed instead. But similarly to presence and PROM, results for acceptance weren't significant ($F(1, 25) = 0.008$, $p = 0.928$, $p_{adj,tukey} = 0.979$).

5 Discussion

5.1 Questionnaires Discussion

On average, questionnaires' scores are high, meaning that overall the participants felt engaged in the simulation, and showed interest and acceptance for the use of this technology to learn more about the traditional sport that is real tennis. The level of presence is high in both contexts of the experiment and we note that participants' feedback show no discomfort (**G6**: $m=5.41, \sigma=1.67$). This gives a good indication that the VR application is working properly and that the participants had an enjoyable experience. Particularly, the high mean score for the construct PROM supports the value of using VR technology for the preservation and promotion of real tennis. It is particularly important to note that the questions on pleasure (U6 and U7) have particularly high averages with a fairly low response gap, showing a fairly unanimous feeling among the participants. The questions on usefulness for heritage preservation (**G1**) and the impression of having learned new things (**G4**) also scored highly (> 6). As a result of these observations, the level of confidence in the usefulness of our VR application for the preservation and promotion of real tennis is high.

However, based on the low scores in both groups for the TRAIN construct, this simulation appears to be not yet convincing enough for the training and practice of the sport. Although this objective was not a target for this work, the user feedback on the subject raises legitimate questions about the use of our simulator for sports practice. The information gathered during these initial user studies does not allow us to identify any particular causes to explain the results obtained on this aspect of the VR application. However, we can put forward a

few hypotheses which constitute research avenues for improving the simulator. An important aspect of sports training applications is bio-fidelity, which concerns the credibility of the behaviour and movements of the virtual opponent, the physical behaviour of the ball during collisions with the racket and obstacles on the court, as well as the user's perception of the interactions, particularly the weight of the racket. It is thus important to consider these different aspects to improve the experience proposed to the users.

We also observed a positive correlation between question U4 and the number of attempts during the chase tutorial ($r = 0.50, p = 0.047$). Perhaps the level of challenge felt by the subjects made them more likely to think that this VR simulation was worth using for real tennis training. It can be interesting to propose training sessions on certain aspects of real tennis, or certain phases of the game, by proposing progressive challenges to the players in order to build on their motivation and competitive spirit. Furthermore, a statistically significant difference was observed between the participants in the gym and those in the historical court, with the former giving lower scores on the TRAIN construct. Two main differences between the two populations may have played a role in this difference: The first being location, it is possible that being physically on the real court represented in the virtual environment had a positive impact on the feeling of playing real tennis in a real situation. The second is age, which was higher in the XP1 population than in the XP2 one. This could be related to the relationship between age and sport, but it is difficult to conclude without further experimentation.

5.2 Historical Court Presence ambiguity

Looking at the standard deviations of the participants' answers, it is interesting to notice that variability is higher in the XP1 dataset compared to the XP2 dataset, especially for the presence questionnaire. The reason may be attributed to age differences between the two groups. Additionally, some questions from the presence questionnaire, such as P4 and P6, may have been confusing in the Court condition, as the VR environment simulates this setting so the notions of real and virtual environment overlap.

5.3 Impact of Location on Presence, Acceptance and Cultural Heritage and Sport Promotion

The results were not conclusive enough to be able to say whether or not location had an impact on the different mean scores. The main assumption, although not testable, would be that the different constructs are independent of location as the VR simulation isolates the user from their real environment, in particular vision, so that what may vary visually in reality should not have an impact on the constructs studied. On the other hand, it is important to nuance these results as it should be noted that the discrepancy in average age between the XP1 and XP2 participants may have included a bias.

6 Conclusions

We presented the design and implementation of a VR environment dedicated to the preservation and promotion of real tennis. The environment offers a discovery of real tennis through a tutorial implemented with a scenario engine, and a free visit of the reconstructed historical building and the practice of the sport.

We conducted an experiment with users to assess the quality of experience and usability of a VR environment for the preservation and promotion of real tennis. The results revealed positive user feedback and corroborate the interest of the approach for the objective set at the beginning.

The user feedback encourages us to investigate new aspects and objectives for real tennis in virtual reality, particularly with regard to its use in sports practice. For this, we will rely on a collaboration with a national real tennis federation which will allow us to work directly with high level players.

VR has the potential to play a significant role in the preservation of traditional sports in ICH. The technology allows for the creation of engaging and immersive simulations that can bring intangible cultural heritage to life and increase accessibility to preservation efforts. As VR technology continues to evolve and become more accessible, it is likely that we will see more innovative uses of VR in traditional sports preservation and ICH more broadly.

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