frontiers | Frontiers in Virtual Reality

TYPE Original Research
PUBLISHED 17 August 2022
DOI 10.3389/frvir.2022.922415

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Technologies for VR, a section of the journal Frontiers in Virtual Reality

RECEIVED 17 April 2022
ACCEPTED 04 July 2022
PUBLISHED 17 August 2022

CITATION
Gaugne R, Barreau J-B, Duc-Martin P, Esnault E and Gouranton V (2022), Sport heritage in VR: Real tennis case study.
Front. Virtual Real. 3:922415.
doi: 10.3389/frvir.2022.922415

Sport heritage in VR: Real tennis case study

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Traditional Sports and Games (TSG) are as varied as human cultures. Preserving knowledge of these practices is essential as they are an expression of intangible cultural heritage as emphasized by UNESCO (General Conference of United Nations Educational, Scientific and Cultural Organization, at its 25th session, 1989). With the increasing development of virtual reconstructions in the domain of Cultural Heritage, and thank to advances in the production and 3D animation of virtual humans, interactive simulations and experiences of these activities have emerged to preserve this intangible heritage. We propose a methodological approach to design an immersive reconstitution of a TSG in Virtual Reality, with a formalization of the elements involved in such a reconstitution and we illustrate this approach with the example of real tennis. Real tennis 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 by every layer of the society. It is still practiced today in few courts in world, especially in France, United Kingdom, Australia and USA. It has been listed in the Inventory of Intangible Cultural Heritage in France since 2012.

KEYWORDS

sport heritage, virtual reality, intangible heritage and popular culture, real tennis, intangible heritage virtual reconstruction method

1 Introduction

In this work, we propose a methodological approach to design an immersive reconstitution of a traditional sport in Virtual Reality (VR) that addresses the different challenges of intangible heritage preservation, with traditional cultural context reconstitution, complete game simulation, and accurate reproduction of physical activity. This approach is based on a formalization of the elements involved in such a reconstitution and we illustrate the method with the example of real tennis.

Traditional Sports and Games (TSG) have been declared in (UNESCO, 1989) as part of Folklore, Traditional and Popular Culture, by the 1989 Recommendation on the Safeguarding of Traditional Culture and Folklore and have since been applied by UNESCO in relation to “Intangible Cultural Heritage”. As such, preserving knowledge of these practices is essential to assert cultural identity of different peoples and social groups, and bring them together. Traditional Sports and Games are as diverse as human

cultures, as explained by (Linaza et al., 2013). There exists many works that identify, document, and classify TSG as mentioned by (Bronikowska and Groll, 2015), mainly with an anthropological, ethnological or sociological perspective.

The preservation of TSG is an important but complex task with multiple obstacles. Real environments associated with TSG are often modified or destroyed for multiple reasons (war, politics, incidents, rehabilitation, natural degradation ...), and the activity can no longer take place there. Virtual reconstruction based on 3D technologies allows to preserve the places and the related activities in a digital form. TSG also suffer from the lack of transmission and communication, leading to the decay of number of participants and then their disappearance.

In order to remedy this, VR represents an interesting solution to reinforce the promotion and mediatization of these sports. Digital reconstruction of buildings and heritage sites usually focuses on visual and architectural representation. However, the complete integration of these environments in which interactive virtual reconstructions of human activities evolve is also very promising for the preservation of these activities, especially since they allow a sensory-motor activity of the user. It is therefore natural to propose virtual environments where a user can discover and experience simulations of TSG.

For Lim et al. (2013), the study of life activities that are important to preserve, and the advances that have been made in terms of 3D production and animation of virtual humans, have enabled the growth of simulations and interactive experiences of these activities. Among the various examples of TSG simulations in virtual or augmented reality, we can identify three main approaches.

The first family of TSG reconstitution focuses on the enhancement of a virtual visit of a site. As an example (Vlahakis et al., 2001), propose a tour of the archaeological site of Olympia with an augmented reality system that simulates some antique sport activities. Another example is a simulation of diving from the Stari Most bridge, from the city of Mostar in Bosnia and Herzegovina by (Selmanovic et al., 2018). This traditional activity practiced since 1664 has given rise to annual diving competitions, accompanied by festivities. The bridge was destroyed during the war in Bosnia and Herzegovina, in 1993, and rebuilt in the early 2000s. The application combines 360° videos and VR to present the history of this bridge and the sports traditions linked to this place, and proposes to the visitor a simulation of a dive from this bridge. In both cases, the objective is not the sport itself, but the presentation of a living context of the site, in order to propose an enhanced experience to the visitor.

The second family of TSG reconstitution focuses on the sport or game flow. In this case, the aim is to document the sport by implementing the rules. This approach is more related to game simulation than sport simulation, in the sense that it does not consider the physical activity dimension of the real player. However, this approach can be interesting in the case of sports with complex rules. Setiawan et al. (2017) propose Benthix VR, a simulation of Benthik, an Indonesian traditional game. This agility game was very popular in the past, but it is rare to see children playing it in Indonesian cities today. This can be due to many factors, such as the acculturation and assimilation of foreign cultures, the growing number of digital games, the lack of documentation and the lack of a playing area. The game has very strict rules and only requires two sticks and two stones to play. The authors present a simulation of the game in VR that implements the rules. The virtual environment does not integrate heritage aspects, the graphical environment is completely neutral.

The last family of TSG reconstitution focuses on the practice of the sport, and especially on the motions and gestures performed by the user. The goal is the preservation of movements. O'Connor et al. (2014) propose a virtual environment to perform and evaluate sport movements of traditional Gaelic sports from Ireland and Basque sports from France and Spain. The evaluation of movements is based on motion capture techniques. Several works on traditional archery, as with (Geiger et al., 2010; Thiele et al., 2013; Butnariu et al., 2018) explore virtual environments that provide physical feedback with haptic systems. There is also a trend in dance practices with numerous use cases that has been going on for almost 20 years, with e.g., work done by (Tang et al., 2002; Nussipbekov et al., 2014; Doulamis et al., 2017). These different works focus on the training of movements of physical activities, but do not propose complete reconstitution of a sport match or game flow.

VR is also widely used for many contemporary sports, mostly for high level competition training as presented by (Bideau et al., 2009; Farley et al., 2020), but also for sport development and promotion as pointed by (Plante et al., 2003). The effects and objectives of VR in sport are well documented and have been for many years. Among the most common ones, we can mention first of all the transferability to the real world, as well as the democratization of the practice and its learning, as underlined by (Katz et al., 2006). There are also more specific uses, such as performance improvement, rehabilitation and well-being.

In the work presented above, related to the representation of TSGs in VR, we note that there is no general method or model to drive the design and implementation of such an application. The effort usually focuses on modeling one aspect, such as the game flow model proposed by (Setiawan et al., 2017), or the physical model for realistic haptic feedback as proposed by (Butnariu et al., 2018). Nevertheless, we did not find a complete representation of the elements characterizing a TSG for the purpose of designing and implementing a VR reconstruction. We propose in the rest of the paper an identification of these elements and a structured methodology to design and implement such a reconstitution. Then, we illustrate the approach with the implementation of a VR application for real tennis. As a result,

we present first elements of evaluation of the resulting VR application, including performance tests, a preliminary pilot study and the interview of high-ranked players. We finish with a discussion on the proposed model and current implementation.

2 Methods

In our work, we focus on the design of a model that describes the main characteristics of a traditional sport in order to implement a simulation of this sport in VR. We propose an identification of the different elements that constitute and characterize a TSG, and we target a user-centered simulation where the user is involved in the practice of the TSG. We illustrate our approach with a particular traditional sport, the Real tennis, or *Jeu de Courte Paume* in French.

2.1 Aims of a virtual simulation of a TSG

VR for TSG reconstruction and simulation makes it possible both to reconstruct environments, places, play spaces, and to simulate the activity that was practiced historically in these places, through virtual objects and interactions. We can identify three different and complementary goals for a TSG reconstruction, that are tightly related to the three families of TSG reconstruction presented in the previous section.

The first objective is the preservation of the TSG as part of folklore, traditional and popular culture. In this perspective, the TSG must be considered in a more general socio-cultural and historical context. VR applications support the representation of such contexts, with multi-sensory and multi-modal interactive simulations, and are already widely used for this purpose.

The second objective is the diffusion and promotion of TSG. It is a question here of giving the possibility to a large public to discover and be initiated to TSG as a game or sport. VR, with its dematerialized nature, and its power of attraction, offers relevant capacities to reach this objective.

The third objective is the realistic practice of TSG. The simulation must offer a faithful and convincing experience to the user, especially in a sports training perspective when TSG is still practiced in a competitive context as is the case for traditional archery and real tennis.

In order to design a model for TSG reconstruction, we seek to address these three purposes.

2.2 Towards a model for virtual reconstruction of TSG

The next step in our work is to identify the main characteristics of a TSG. We consider that a TSG confronts one or more players with a ruled environment to challenge specific skills, and that it is associated with cultural and social contexts. This definition places the TSG at the center of the reenactment and establishes an explicit relationship between the user-player, his or her activity in the TSG, and the context of the TSG. Associated with the different objectives presented above, this description allows us to identify three main components in the reconstruction of the TSG linked to a user-player approach, the *Player*, the *Game*, and the *Context*.

1. The Player. At the center of the simulation, the user-player is connected to the environment through an *Equipment* that allows him/her to interact, and he/she is involved through tested skills such as agility, intelligence, strength, speed, endurance, stamina, memory, skill, ingenuity, etc. as presented by (Billing, 1975). We can distinguish two different types of skills, *Mental skills* and *Physical skills*. This part is related to the human activity performed by the player while acting in the sport. In this part, we base our approach on the study and reproduction of the perception-action loop that is commonly used in VR environments dedicated to high level sports training, following the approach of (Bideau et al., 2009). The challenge is to display to the player all the necessary information to provoke a realistic reaction, to stimulate the targeted skills, and to foster natural movements as close as possible to real ones.
2. The Game. This part is composed of the physical place where the sport is practiced, which we call *Static Environment*, of different dynamic components involved in the game such as physical objects (ball, arrow, …..) or simulated characters (partners or opponents) that constitute a *Dynamic Environment*, a set of *Modes* (single player, single player vs virtual, team, …), of *Phases* and of *Rules* that describe the *Flow* of the *Game*, and of the evaluation criteria that define the *Arbitration* and the *Scoring*. The dynamic environment is the most complex part of the implementation phase because it involves a physical simulation of some elements (e.g., the trajectory and bounce of the ball), and/or a behavioral simulation of virtual partners or opponents.
3. The Context. This part is less directly linked to the practice of sport, but is an important aspect to take into account in a reconstruction of intangible heritage, because it aims to represent the associated *Historical*, *Cultural* and *Social* context. VR allows this representation which gives meaning to the reconstruction. It consists of the architectural environment, the game's props, the representation of the social context (sporting public) and the historical elements.

The different characteristics are displayed in Figure 1. It is important to notice, that this model puts the TSG at the center of the reconstitution, and enables a complete representation that allows to consider the preservation of its cultural identity, its intangible nature with the reproduction of human activity, and

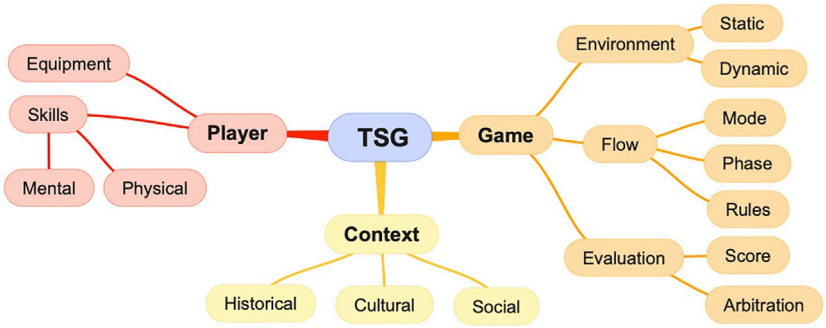

FIGURE 1
Characteristics of TSG.

TABLE 1 Characteristics for Bridge dive, Benthik, Traditional archery, and real tennis.

			Bridge dive Selmanovic et al. (2018)	Benthik Setiawan et al. (2017)	Archery Butnariu et al. (2018)	Real tennis
Player	Equipment		-	Stick	Bow	Racket
	Skills	Mental	Courage	Strategy	Concentration	Strategy
		Physical	Agility	Agility	Agility, precision	Agility, strength, endurance
Game	Environment	Static	Bridge with diving board	Wok represented by two stones and one short stick	Shooting point and target in an external natural landscape	Court with surrounding walls and penthouses
		Dynamic	Water, flotation	Virtual opponent	Arrow, bow haptic feedback	Ball, virtual opponent, sounds
	Flow	Mode	Single real player	Real vs. Virtual player	Single real player	Real vs. Virtual player
		Phases	-	3 rounds	-	Change of side and service
		Rules	-	Rounds	-	Service, chases, points and fouls
	Evaluation	Score	-	Round winning	-	Points 15, 30, 40, game 1 to 6, set best of 3
		Arbitration	-	One referee	-	One referee
Context	Historical		Reconstitution of the bridge and its History	Not represented	Representation of ancient archery with traditional bows and targets	Reconstitution of a 17th c. building with representation of crowd
	Socio-cultural		Presentation of the associated festival	Not represented, neutral generic opponent	-	Representation of a popular crowd with both male and female characters

its tangible context with the integration of material elements such as the associated equipment and buildings.

2.3 The real tennis case

We illustrate our approach with the real tennis, a racket sport that has been played for centuries and is considered the ancestor of tennis.

Table 1 proposes an identification of the different characteristics of real tennis, according to the model presented in the previous section, and compares it to the characteristics of three other TSG reconstitution presented in the previous section, Mostar's bridge dive, Benthik, and Romanian traditional archery.

This comparison highlights the differences of approach and goal of the different reconstitution. While the Bridge dive focuses on the Historical and Cultural context, the Benthik reconstitution focuses on the game flow with no intent to represent the cultural aspects, and the traditional archery simulation focuses on the physical activity realism with no representation of a traditional tournament and very limited representation of the Historical context. We consider that the combination of all these elements is important to represent any TSG in a VR application, in a will of preservation, promotion and learning or practice.

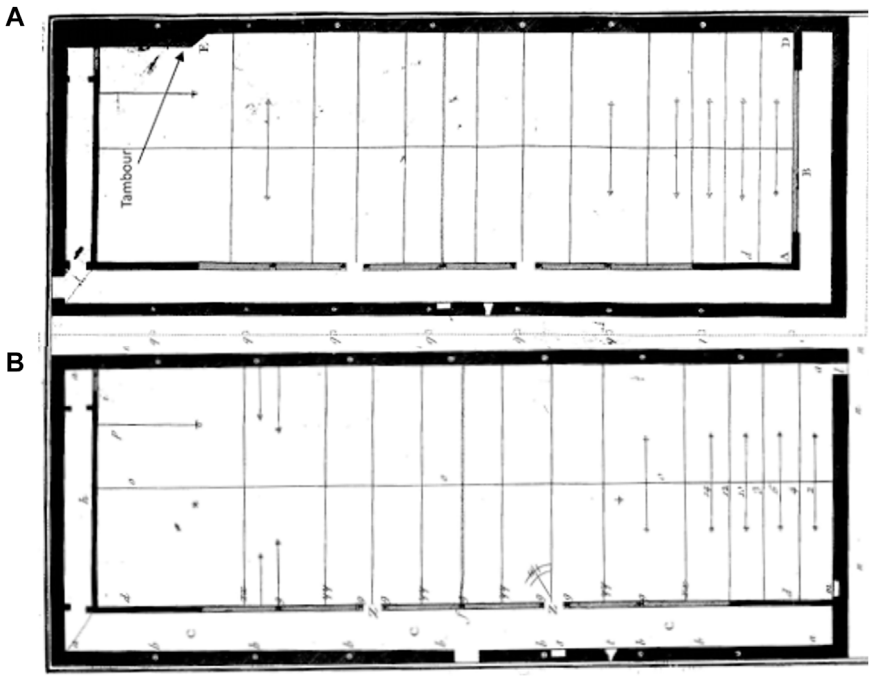

FIGURE 2
Comparison between real tennis courts: "Dedans" court **(A)**, "Quarré" court **(B)** Ferrette and Esnault, (2016).

In this section we detail these different characteristics, starting with the context, as it makes it easier to have a general vision of the interest of the game, then the player, and finally the game itself.

2.3.1 The context of real tennis

Real tennis has an important historical interest in European culture. Before tennis came along (Potts, 2007), declares that "Jeu de Courte Paume" or "real tennis" was "all the rage in Renaissance Europe". It is widely studied in France as e.g., by (Mehl, 1990; Carlier and Bernard-Tambour, 2002; Clastres and Dietschy, 2009). It was practiced by every layer of the society, by women as well as by men, and it was not uncommon to attend mixed matches. In particular, it has left important traces in the French culture where many expressions of language still used today come from this sport.

Real tennis was played since the 15th century in dedicated buildings, either in aristocratic estates or in city centers. After the decline of real tennis, 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 m wide and 30 m long, facilitate their identification.

Real tennis is still played, mainly in France, Great Britain, the United States 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.

In real tennis, there exists two variants, the "Dedans" game and the "Quarré" game. Modern Real tennis courts are all implementing "Dedans" version of the game. There exists only one "Quarré" courts still in activity, the Falkland Palace Royal Tennis Club (https://falklandtennis.wordpress.com/). Trinquete courts used for pelota in Basque country and in South America can also be used for the "Quarré" variant of real tennis. The rules and the architecture of the court are slightly different from one to the other (see Figure 2).

2.3.2 The player in real tennis

As a racket sport, real tennis game calls on several physical skills of the player, his/her agility, his/her endurance, and his/her strength. It is also a sport where strategy holds a preponderant place, with complex rules of the game which have earned it the nickname of the game of tennis chess.

The equipment is mainly the racket even if at its beginning, real tennis was also practiced with bare hands, with the palm, or with a leather glove. The racket was definitively imposed in the 16th century, and was made in a traditional way, out of wood with a stringing sieve. The balls were also hand-made, following

FIGURE 3
Balls and racket are still assembled by "Maîtres Paumiers".

methods that have changed little down the centuries. Rackets and balls are still handcrafted today (see Figure 3), assembled by the "Maîtres Paumiers", who are the managers of real tennis courts.

The racket is made up of a handle and a head, all measuring about 68 cm long and weighing between 350 and 380 g for adults; for children under 14, rackets may be shorter or lighter. The sieve is a set of crossed and intertwined strings.

From the 1580s, the core of the balls was covered with cotton and no longer with leather as was the case until then. Today, the balls are made by hand. They are made up of various elements of cork, fabrics, string and felt: the heart of the ball is made of cork, surrounded by a strip of cotton, consolidated by a whole series of knots with string, a hand-sewn felt placed on it. The ball is usually white or yellow in color, for good visibility during rallies. They measure 62–65 mm in diameter and weigh 70–80 g.

2.3.3 The game of real tennis

Following the structure of the model proposed in Section 2.2, we detail in this section the static environment, the dynamic elements, the game flow, and the scoring.

2.3.3.1 Static environment

The game is played inside a dedicated building, on a court separated into two parts by a net, the Service side and the Hazard side. The net was often a simple rope in ancient courts. The court is surrounded by two (Quarré version) or three penthouses (Dedans version), covered by a sloping roof (see Figure 4). The openings in the penthouse are well defined but can vary a little from one court to another. Some specific areas in the court are associated to scoring ruled, such as the *Winning Gallery*, and the *Grille*. The chase lines on the ground were not always marked on the ground in ancient courts. In this case, the active chase was marked using a chalk.

2.3.3.2 Dynamic environment

We consider two dynamic elements in the real tennis simulation, the ball and the virtual opponent.

The ball: this element is associated to a physical simulation. The physics of the ball is central in the simulation as it conducts the player activity and strategy. In real tennis, the player has the possibility to use bounces on the walls and penthouse roughs. Due to its structure, the ball course speed is quite low compared to tennis and bounces are weak. It is thus important to measure the physical behaviour of the ball to implement a realistic physical simulation.

The virtual opponent: it is defined by three characteristics: 1) a graphical aspect, which relies on the historical context of the reconstitution, 2) animations that represents movements performed while playing the game, but also can be enriched by emotional animations according to lost or winning points, and 3), a behavior or Artificial Intelligence (AI, in the sense used in video games implementation, not related to the general AI research domain) of the virtual player that defines its game strategy and drives its moves and gestures. Different behaviors can be implemented to offer variability in the game play.

2.3.3.3 Game flow

We focus on a single-user mode as we are first interested in the reconstitution and simulation of the TSG itself, but we propose in the final discussion some tracks and challenges for the extension of our method to multi-players modes.

The phases of the game are structured by the chases which entails a change of side of the players, and the a change of serve, as the serve is played only on the Service side.

This game has very specific rules with respect to modern tennis, in particular due to the a complex system of chases. Moreover, the serve is played differently than in tennis and is

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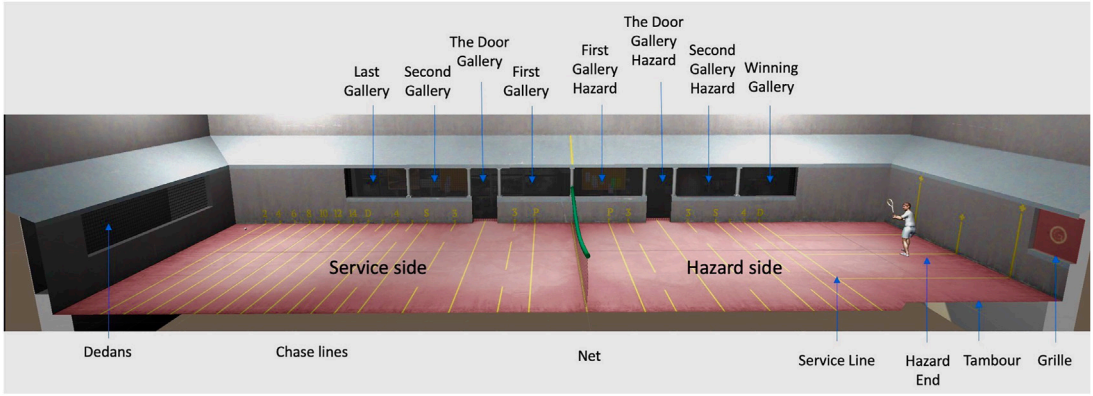

FIGURE 4
Overview of a "Dedans" court (the court of Fontainebleau).

very important in the game because it gives the server many advantages.

The rules are structured around the serve, the chases, and some specific points and fouls. We will not present all the rules in detail, but try to sum up the main aspects.

Serve: The objective for each player is to do everything possible to take the serve, which comes at the beginning of each point, and keep it as long as possible. The server is allowed two serves, but must always serve on the Service side ("Dedans"), between the "Dedans" wall and the Second Gallery Line, without having a foot on it (see Figure 4).

The service is valid if the ball makes at least one bounce on the service roof on the Hazard ("Devers") side and the following condition: either it falls into the service box, or after touching the service roof, it enters directly into the "Grille" or the last opening of the Hazard side without touching the floor. A serve can be put back into play and is then called a pass serve in certain cases: if, after touching the roof, the ball bounces against the big wall and/or falls into the passing box. A service foul occurs if the server serves from the wrong place, makes an invalid serve, misses the ball while trying to hit it, or makes two consecutive passing serves.

Chases: A chase is a "pending" point or a "restart" of a point following a second rebound of the ball in a particular area of the court called the "chase area," where there are lines called "chase lines" drawn on the ground. It is played when the players change sides, which depends on the state of the chases and the current score. A chase is called if the ball takes a second bounce in a chase zone, or enters one of the side openings, or hits a post at the openings and the net after zero or one bounce. The walls and gallery sloping roofs (penthouses) do not count as a rebound.

When there is a chase, the line on which the ball made its second bounce is announced. The score does not change, the game continues as normal and the position of the chase is kept in memory. If one of the players has "40" or "advantage," chased are played after the side change. If these scores are not reached but it is the second chase in the game, the side is changed and the two chases are played in the order in which they occurred.

The defender is the player who initiated the chase. His opponent is called the striker. Before the chase is played, the score is announced followed by the chase name. To win the point, the striker's aim is to make a better chase than his opponent, i.e., he must aim at a chase line closer to the wall (on the other side of the court) than the defender's. The role of the defender is to defend his territory and prevent the striker from making a better chase, or to make him make a worse one, in which case the point is awarded to him.

Points and fouls: If one of the players makes a direct foul during the chase, then it is cancelled and the other player wins the point. Similarly, a direct point will also cancel the chase. If the striker makes a chase equal to that of his opponent, then the chase is declared null, the score remains unchanged and the match resumes as normal. On the other hand, if the defender of the chase makes a new one, he wins it. Each player makes a mistake and/or loses the point, if he:

- does not return the ball until the second bounce, unless it is "chased".
- loses a chase
- hits the ball more than once with the racket
- sends the ball out of bounds
- does not throw the ball over the net
- hits the ball against the wall on the opponent's side and the ball returns to his side without touching the ground
- makes a double foul on the serve

The returner gets a direct point only if he wins a chase or if his opponent makes a foul. The server gets a direct point if he:

- wins a chase

- sends the ball into the "Grille" or into the last opening of the "Devers" side
- serves correctly by touching the service roof and the ball goes directly into the last opening of the "Devers" side or the "Grille" without touching the ground
- his opponent makes a foul

2.3.3.4 Scoring

Score: Having inspired tennis, the scoring is similar but the announcement has its own particularities. At the beginning of each game, "nothing in the game" is announced. The points are then counted and announced as follows: "15" (first point), "30" (second point), "40" (third point). The player who scores his fourth point wins the game unless both players are on "40". In this case, "two" or "tie" is announced, then "advantage" for the next point. If the player with the advantage wins the point again, he/she wins the game, otherwise it is back to a tie. So a player needs to score two consecutive points to win the game at this stage. The score is always announced by naming the player who won the point first. The announced score will be followed by ". . .for the Dedans" if the server has scored the point, and ". . . for the Grille" if it is the receiver. The first to reach six games wins the set. In the current version of real tennis, a match is maximum three sets for women (first to two sets wins) and five sets for men (first to three sets wins).

Arbitration: There is one single referee who is positioned in the lateral penthouse, at the net level. The referee announces the score and chases.

3 Application to real tennis case

In this section, we present the resulting virtual reality simulation of real tennis, based on the proposed method. We first present the context of the implementation, and the 3D reconstitution of the building, then we present the implementation of the VR application, and we finish the section by a presentation of the technical details of the resulting application.

3.1 The context

The project of virtual real tennis was initiated during a collaboration between archaeologists and computer scientist around the study of an ancient real tennis court in Rennes. The building is one of the oldest preserved building of real tennis in elevation in France. It is located in Rennes, Brittany (see Figure 5). It was built at the beginning of the 17th century, named "Le Pélican", but was transformed into a religious chapel at the end of the 17th century, and became the property of the army after the French Revolution at the end of the 18th century [see Banéat, (1972)]. The municipality that owns it since the 20th century asked for an archaeological excavation and a building study in 2014 (see the excavation report in Ferrette and Esnault, (2016)), including a full digitization of its inside and outside before launching rehabilitation works. Due to time constraints imposed by the municipality, the digitization was carried out by 3D laser scanner in a few weeks, as part of the Digital Conservatory of Western Archaeological Heritage project presented in (Barreau et al., 2013), in parallel with the archaeological diagnosis. The large point clouds resulting from this digitization was used as a basis for implementing a framework for an immersive and interactive 3D manipulation for archaeological analysis presented in (Gaugne et al., 2019). The Pélican court implemented a "Quarré" game, with two penthouses around the court.

One goal of the virtual simulation is thus to represent this historical evolution of the building and to propose a reconstitution of the court as it was in 17th century. This 3D reconstruction was performed through the collaboration between archaeologists and computer scientists and is described below.

Now, the Pelican building has been fully restored by the municipality and is used as a multipurpose neighborhood house, hosting a nursery and meeting rooms for associations. Half of the building was arranged as a large room saving the original volume of the real tennis court, with a representation of the penthouse position (see Figure 6).

Another different aspect that we judged important to represent is the fact that real tennis is still played in active courts. In collaboration with the French Committee of real tennis, we considered the integration of a representation of one of the main active courts in France, the court of Fontainebleau, built in 1601. This court has also the interest of implementing a "Dedans" game.

3.2 3D reconstruction

In this section, we will describe various elements that led to a 3D reconstruction basis presented in Figure 7. Starting from the general volumetry, we will then evoke the "mur de bricole," the low and high galleries as well as their accesses, the wooden structure, some annexes, but also some materials and decorations that are fully detailed in the archaeological report by (Ferrette and Esnault, 2016).

The initial volumetry of the building presents a vast nave of 28.90 m by 9.30 and 12.60 m under the roof. The bill of sale of the court to the bishopric in 1686 mentions: "a real tennis court built with stones, wood and Earth". One of the characteristic elements of the court is the *"mur de bricole"* located in our case on the eastern gutter. The *"mur de bricole"* has the advantage of having preserved the trace of a gallery to the north. No remains of the gallery on the west wall opposite to the *"mur de bricole"* could be observed. However, this gallery certainly existed and is attested to by the southern survey carried out during the diagnosis. Contrary

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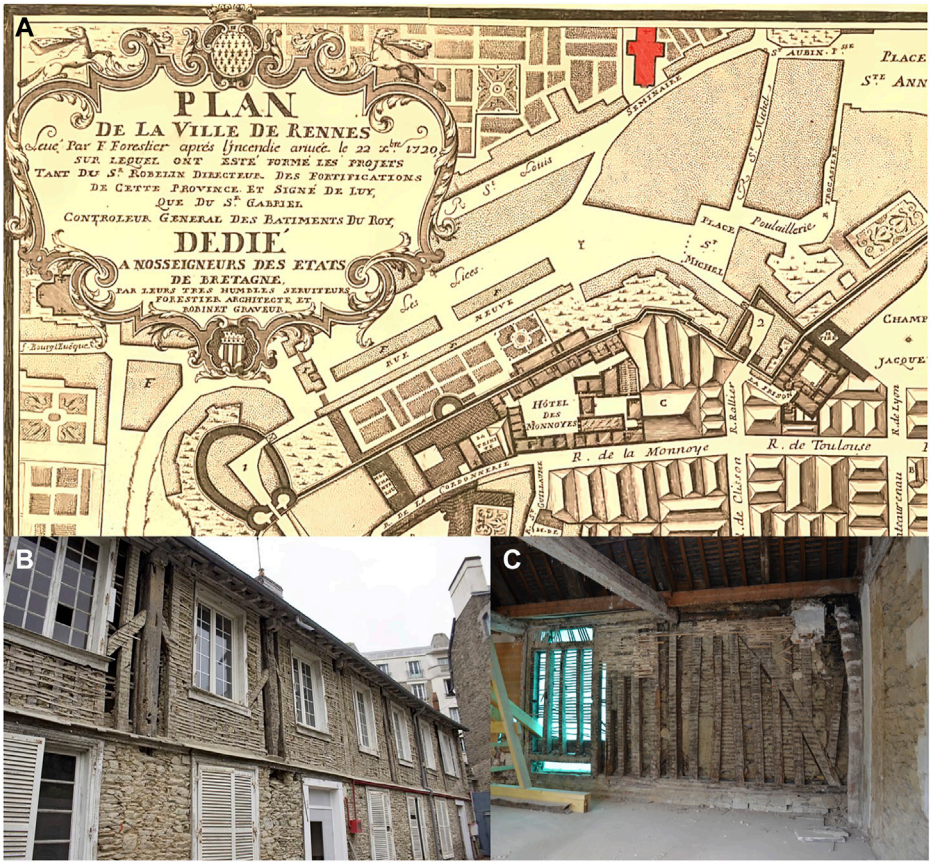

FIGURE 5
Location of the building (in red) as a chapel on a plan made after the fire in Rennes in 1720 Andrieux, (2021) **(A)**/interior **(B)** and exterior **(C)** views Ferrette and Esnault, (2015)

to the north gallery having kept its imprint on the *"mur de bricole,"* no trace of south gallery could be highlighted. This makes it possible to attest that the court was indeed dedicated to "Quarré" game, because comprising only two galleries and having no "Tambour" to the south.

The high galleries, which have now disappeared like the low galleries, can nevertheless be reconstructed thanks to the numerous clues left by the posts, and in particular the orphan mortises visible only on the posts of the west and north facades. If the external gallery is attested by the archaeological study, the existence of a staircase to access it is indisputable. One source gives a relatively accurate description of the staircase and its function: "a small stable made of wood and terrace covered with slate on the lower side containing ten and a half feet long and eight and a half feet wide adjoining the housing of the court without lining by which stable is the passage to go up to the galleries of the court". A plan of 1801 indicates the presence of a staircase at the north-western corner of the former court.

The bill of sale of 1686 indicates that the court is paved and tiled. Indeed, among the oldest floors, the simultaneous use of 16/16 tomette and granite paving has been observed. Despite the very partially preserved floors, we have the delimitation of the playing surface, which also corresponds to what was observed in elevation. The floor makes it possible to determine the width of the western gallery, of which no trace could be found during the study.

The analysis of the wood structure reveals a high degree of overall homogeneity. The framework is indeed original, as the dendrochronological datings attest, but it is not impossible that it has been repaired from time to time by dismantling and reassembling a part and reassembling the parts in a different order.

Several sources mention the buildings that occupy the parcel. Among them, a laundry room and a laundromat are clearly related to the game. Indeed, according to the real tennis expert associated to the study: "When the game is over, one goes up to a room, where there is a good fire, in front of which one is rubbed naked and wiped down by the boys of the game; when this is done, one takes on one's clothes: beds are no longer given as they used to be, because of several disastrous accidents that have

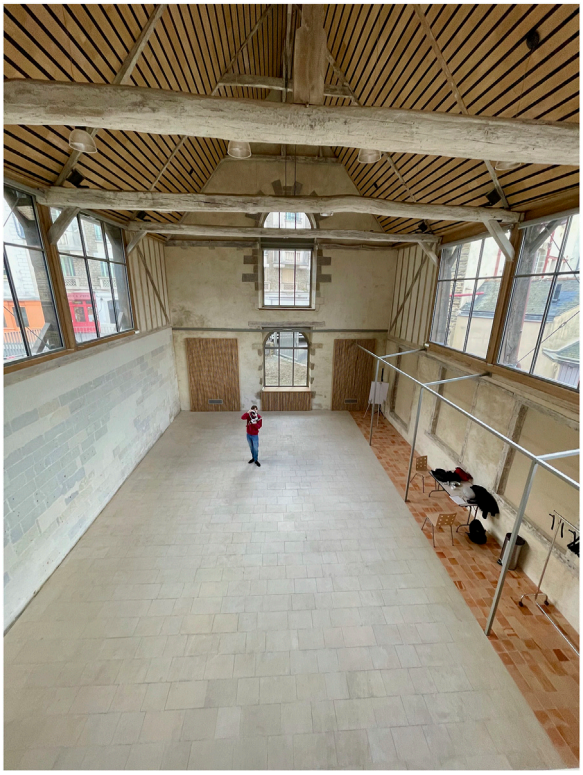

FIGURE 6
Inside view of the restored building.

occurred for having fallen asleep in them . . . ". Another essential element of a building receiving the public is the latrine. Although archaeologically speaking the latrines uncovered in the north-west corner of the building are not strictly contemporary with the court, they were certainly built very quickly and may be part of one of the repair phases mentioned in 1638.

As the simulation took place indoors, we then focused the mesh reconstruction work on the interior textures and characters.

Most of the elements have been textured with generic sources by conforming as closely as possible to the archaeological information mentioned above. Like the ancient wall of the Portes Mordelaises in Rennes (Barreau et al., 2020a), the *"mur de bricole"* strongly marks the identity of the place, and we wished to rework with Photoshop an orthoimage realized during the archaeological study in order to propose a large texture of rather good definition corresponding to its original state.

As an extension of a previous work by (Barreau et al., 2020b), the virtual humans acting as opposing players and populating the audience (see Figure 8, top) were created with Adobe Fuse CC. This software offers a library of body parts, clothes (tops, pants, hats . . .) and textures. It also carries out the assembly of these various parts, their possible deformations and the application of various textures. The virtual characters integrated in the simulation were consistent with the period.

As a complement we integrated a 3D model of the Fontainebleau court made by a private company for a public exhibition. This model was provided to us with full rights of utilization in our simulation. A view of both 3D models is presented in the bottom part of Figure 8.

Two models of rackets were also proposed, one from 17th century, and one modern racket (see Figure 9).

3.3 VR application

The implementation of the virtual reality environment for real tennis follows the method presented in Section 2. The virtual reality environment proposes to the user a first-person experience where he/she is a player facing a virtual opponent.

- The player skills: the user handles a virtual racket in his hand and interact with his/her full body to confront a virtual opponent.
- The rules of the game are implemented, with the different phases of the game, the serve, the chases, and the score. In order to help the understanding of the game, several dynamic graphical elements enhance the visual environment, a vizualisation of the trajectory of the ball, a scoreboard, and a visualization of an active chase area (displayed in green on the ground, while the rest of the ground is displayed in red) (see Figure 10). The implementation of the dynamic environment, the ball, the animated characters, and the graphical elements, is presented below in this section.
- The environment is constituted of the two alternative courts presented above, The 17th century court Pelican ("Quarré") with a crowd to represent a public from this period in the upper gallery, and the contemporary court of Fontainebleau ("Dedans").

3.3.1 Features development

The project is developed under the Unity engine, to display, move and make the objects interact together. The Unity OpenXR and Unity XR Interaction Toolkit packages are used to allow the management of VR-related equipment and to implement the VR interactions. The UML diagram in Figure 11 summarizes all the scripts realized as well as the aggregation links connecting them. The game main system is the *GameManager* class which has the role of managing the actions, the general game data and the interactions between the others subsystems. The *GameManager* script is linked to a *PointCounter* class that maintain a record the game score.

The display system is the simplest, it consists of two scripts *ScoresDisplayer* and *ChaseDisplayer* and allows the updating of the display panels present in the scene by the *GameManager*. The

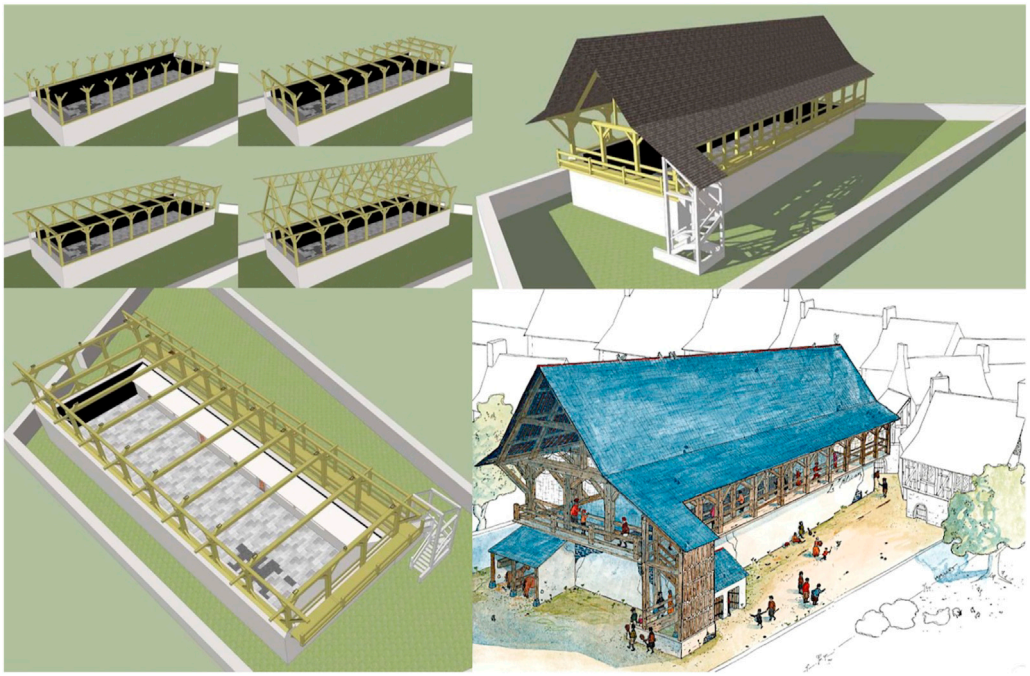

FIGURE 7
3D reconstruction of the building with assembly of the wooden structure, the staircase, the latrines, the roof (© E. Esnault) and hand drawing over the 3D reconstruction (© M. Miller) Colleter et al. (2021)

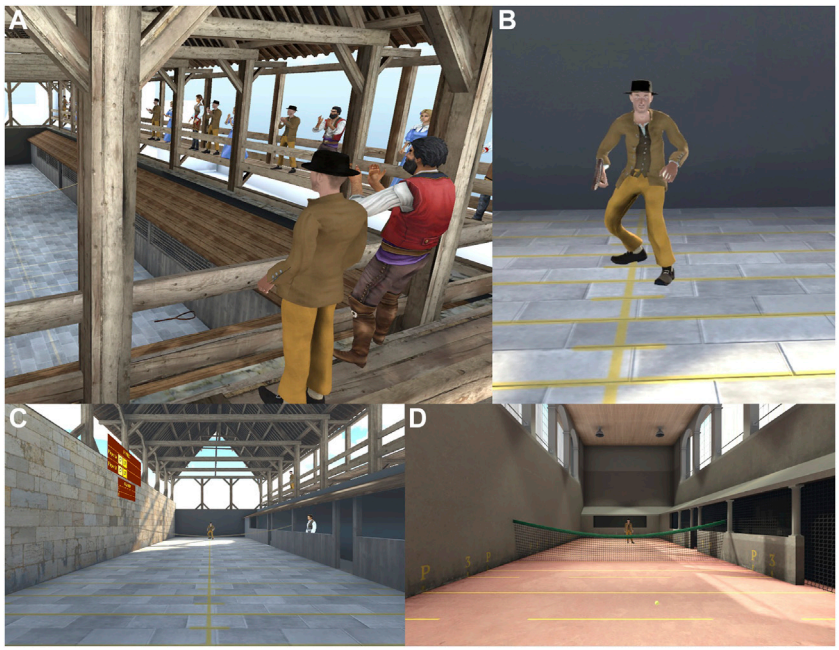

FIGURE 8
Top: The characters populating the virtual simulation: the public **(A)**, and the virtual opponent **(B)**. Bottom: Two versions of courts, 17th century court of Le Pelican, Rennes **(C)** and actual court of Fontainebleau **(D)**.

FIGURE 9
The two 3D models of real tennis rackets, 17th century racket on the left, contemporary racket on the right.

player's system consists of *VRUser*, to manage the player's actions. The simulation of the virtual opponent is structured around a main script *VirtualAdversary* (see Figure 12). This one gathers all the modules necessary for the functioning of the opponent: management of the virtual player's movements, its shots, its shooting targets and its animations. Each of these modules has a specific function and a particular context of use. Some interact to provide intermediate results and others perform processing to produce a result in *VirtualAdversary*.

Ball is the script that gives the raw information about the ball, making a selection to avoid storing useless information. The prediction of the ball trajectory (see Section 3-3-3) is made by its *TrajectoryPrediction* script. *RoomSettings* defines constants to delimit the court, and especially the set of possible *Chase*. Finally, *RoomSettings* allows to convert *Ball* data into chasing zones. It then communicates this result to the *GameManager* which benefits from a second level of abstraction. There are also various scripts not present in Figure 11 that allow to manage menus and settings.

All physical elements, including the ball, use the Unity built-in 3D physics (Nvidia PhysX). We set the physics refresh rate to 90Hz, a step represents 11.1 milliseconds.

3.3.2 User locomotion

The application was designed to foster 1:1 natural real navigation and movements in a 10 m by 10 m physical space. This represents a realistic game area for real tennis, as the players seldom play near the net.

This design choice constitutes a strong constraint for the use of the application, but this is consistent with the targeted goal of realistic sport training. In order to ease the access and use of the application in a smaller physical space, the first difficulty level of the virtual opponent always send the ball in a close area around the player (see Section 3.3.5). Furthermore, we use a standard target-based travel technique, from the Unity *XRInteractionToolkit* package, with a teleportation arc metaphor, and instant transition to allow the user to visit the building for cultural mediation purposes. Other navigation possibilities are discussed in Section 5.

3.3.3 Real time ball trajectory prediction

The ball trajectory prediction is used for two parts of the simulation. First, it drives computation of the virtual opponent movements, and second, it allows to visualize the trajectory of the ball. This visualization of both past and predicted trajectories can be optionally displayed during the simulation. The activation of these tracks is available in a user menu accessible at any time

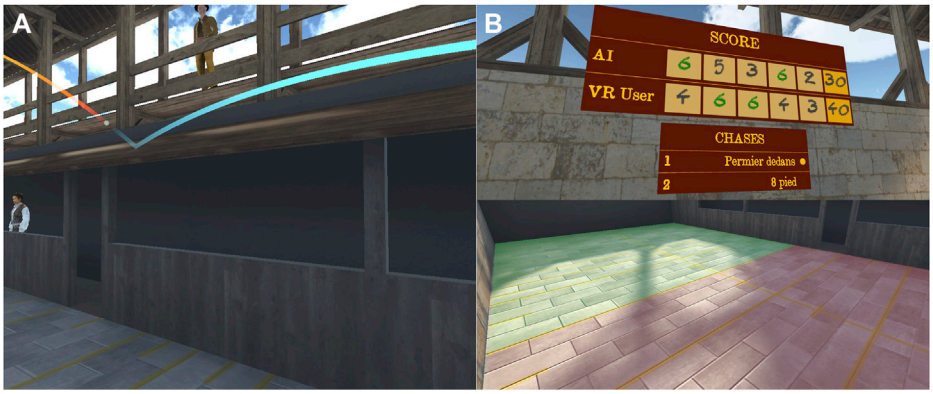

FIGURE 10
Left: Visualization of the trajectory of the ball; Top right: Scoreboard; Bottom right: Visualization of the active chase area.

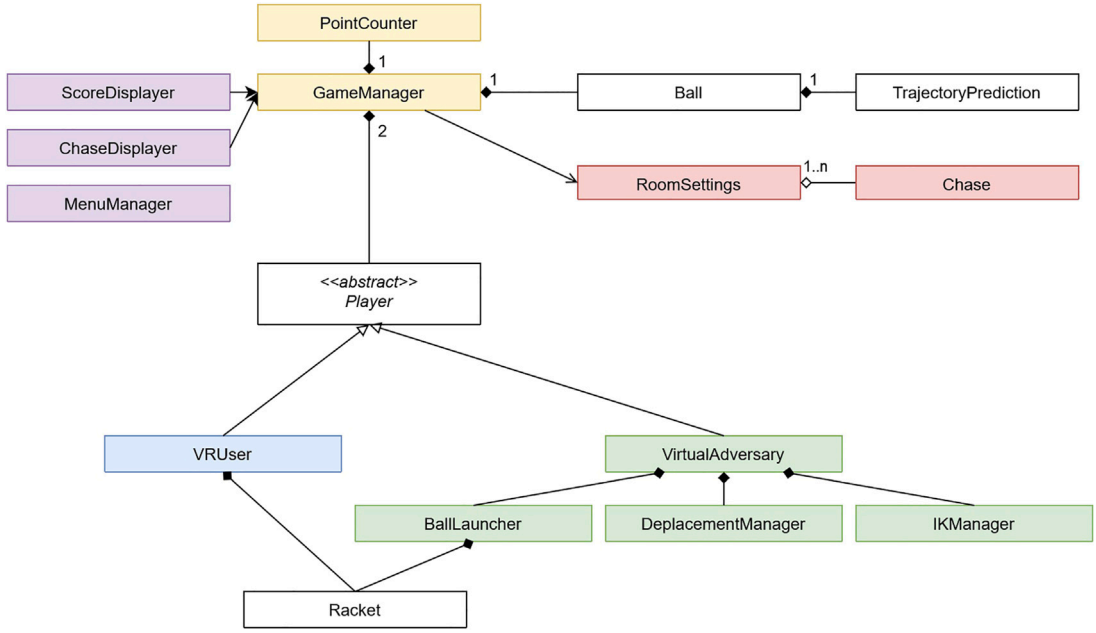

FIGURE 11
Simplified UML diagram of project scripts.

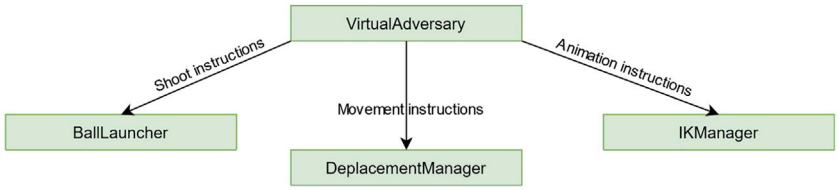

FIGURE 12
Diagram of the virtual opponent management subsystem.

during the virtual experience. Each track can be activated or deactivated independently. The past track is displayed in red, and the predicted track, in blue (see Figure 10).

A first version of the ball prediction used ballistics equations and raycasts to compute bounces. It was computed as soon as the ball was hit by one of the rackets, and limited to two ball bounces ahead. This version was very fast to compute, but did not work in some edge case such as bounces on edges, and globally lacked of precision.

A second version was made to revise these problems. At the start of the application, we copy all statics colliders to a second physics scene, and clone the ball to use it as a dummy for prediction. This second scene is not visible and is used to simulate physic in advance. It has the advantage to use the same physics engine as the visible ball, the prediction is really precise. The only drawback is that it cost more in computation time. To limit the computation time (the application must run on an Oculus Quest 2), we recompute the trajectory only when a racket has hit the ball, because they are the only physical elements that are not predictable. Prediction are stored as discrete positions in a queue: we need to remove the oldest prediction on each real physic step. To ensure a constant refresh rate, when 1 real physic step is computed, a maximum of 10 predictions steps are computed. Furthermore, we limit the prediction to 500 steps ahead (5.5 s). These numbers were determined empirically.

3.3.4 Interaction with the racket and ball

The player interacts with his/her two hands, with one controller in each hand, one to handle the racket, and one to

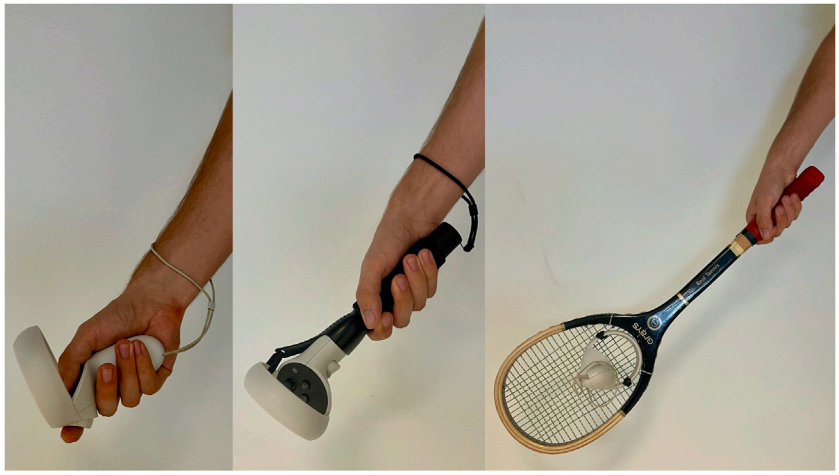

FIGURE 13
Different modes of virtual racket holding.

handle the ball. The grasp of the ball is required only for the service phase. In this case, the payer grasps 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.Holding the racket does not require any button activation, the racket is always attached to the controller while in play mode. We experimented three ways of holding the racket, with an Oculus Quest 2 set up, as presented in Figure 13. These three modes are straightforwardly adaptable to other set up presented in Section 4.1, and work for both right-handed and left-handed people. In the first mode the user holds the racket directly through the controller (see Figure 13, left). This first solution is the simplest one, it has the advantage to be directly usable by any user in the case of a wider distribution of the VR application. In the second mode, the controller is extended with a handle extension grip (see Figure 13, center). This solution has the advantage to be closer to the holding of a real racket. Furthermore, this kind of equipment is accessible trough market sites. The potential risk of this solution is that it exposes the controller to impacts with the surrounding physical environment. In the third mode, the controller is attached to a real racket (see Figure 13, right). This mode is the closest to the real practice, especially because the real tennis racket are quite heavy (370 g) while an Oculus Quest 2 controller weighs only 126 g. This mode is important for the case of sport practice to ensure a more faithful sensation and movement.In order to manage the different modes, a calibration is proposed in a technical menu to dynamically adjust the translation and rotation of the virtual racket with respect to the controller.

3.3.5 Virtual adversary

The virtual adversary uses the ball prediction to move. It can do forehand and backhand strokes, depending on its position relative to the ball. The game system is abstract enough to replace easily the VR user with a second virtual adversary. This means that it is possible to put two virtual players and make them compete one against the other. This particular mode can be interesting to present the game rules to a new player.

The virtual opponent is animated with tennis animations, and is able to serve and maintain an exchange of balls. Its serve is implemented according to the official rules. The virtual opponent has three levels of difficulty for the user. In the first level, the virtual opponent moves with the ball and sends it back on the user. In the second level, the virtual opponent positions itself according to the ball's trajectory and sends the ball on predefined targets in the courts. These targets are placed at easy positions. In the third level, the virtual opponent analyses the game situation (player's and ball positions) in order to sends the ball on targets placed at position that are difficult to send back. At the end of every game, the crowd applauds and the virtual opponent shows its satisfaction or disappointment with a short animation depending on his score.

3.3.6 Score display

Although it does not fully respect a historical representation, we have added a scoreboard, visible in the Figure 10, to help the user better understand the current state of the match. The scoreboard is inspired by the real tennis TV overlay. It displays the scores of current and past sets, highlights the winner of past sets (from the first to the sixth game), and displays the current chases. When the user plays a chase, an

FIGURE 14
Virtual real tennis in a large cave facility.

indicator marks the chase to be beaten or defended, depending on your side. The displays are entirely optional and can be hidden without impacting other parts of the application.

In addition, a virtual referee verbally announces the score at the beginning of each point. He is represented by a virtual character positioned in the penthouse at net level in the Pelican court, visible in the lower left part of Figure 8.

4 Results

This section presents the results obtained from the VR implementation of real tennis following the method presented in Section 2. We first present technical results related to the deployment and test of the application in different facilities, then we present the results of a pilot user-study on presence assessment and an interview of two high-ranked real tennis players.

4.1 Technical results

As presented in Section 3, the project is developed with the Unity engine, and uses the Unity OpenXR and Unity XR Interaction Toolkit packages. Regarding the hardware, we used both HTC Vive and Oculus Quest 2. For the HTC Vive, we used the SteamVR software to connect and use them from the project computer. For the Oculus Quest 2, we used both the "Oculus Link" and "Oculus Air Link" technology to connect to the computer. A compiled android application was also made to run directly on the headset in an autonomous mode. The latter allows us to travel with only the headset and to use it in 10 m by 10 m rooms, without cable annoyance. The virtual real tennis was also deployed in a 10 m large CAVE-like facility (see Figure 14) using the MiddleVR software (https://www.middlevr.com/) support to manage the synchronisation of 14 instances of the application running in parallel on seven computers as required by this particular immersive facility (https://www.irisa.fr/immersia). Usablility of the different configurations for virtual real tennis is discussed in Section 5.

We performed a measure of the number of Frames Per Second (FPS) during a sequence of ball exchange in the different configurations. For the CAVE configuration, we used the FPS from the MiddleVR logs, and we calculated the average of 19 consecutive values corresponding to the sequence. For the HMDs configurations HTC Vive Pro and Oculus Quest 2, we used the module Graphy for Unity (https://github.com/Tayx94/graphy) to display the FPS, and we observed the FPS during 2 min in the sequence. The FPS value never went under the maximum possible FPS for each HMD, 90 Hz for the HTC, and 120 Hz for the Quest with link mode. For the Oculus Quest 2 in autonomous mode, we measured an average of 89.7 Hz on this period of 2 min, with a maximal screen refresh rate set to 90 Hz. The observed average measures are presented in Table 2. The computer used for the two HMD configurations has an Intel i9-9900, 32GB RAM, with a Nvidia GeForce RTX 2080. The

TABLE 2 Performance measurement.

VR condition	FPS
HTC Vive Pro	90.0
Quest2 Oculus Link	120
Quest2 autonomous	89.7
VR Cave	48.5

Immersia platform is using 7 computers equiped with Intel Xeon bi-processor E5-2623, 32 GB RAM, 2 Nvidia Quadro P6000 and Nvidia Quadro Sync II, connected to 14 Barco F90-4K videoprojectors at 2560 × 1600, 120 Hz resolution. The Immersia platform was running an older version of the virtual real tennis with no optimisation of graphical rendering (dynamic shadows). The resulting measures demonstrate a fluid rendering of the VR application in HMDs, which is important to prevent cyber-sickness issues.

4.2 Pilot user-study

In order to prepare a larger assessment of the application, we conducted a preliminary pilot user study focused on presence evaluation, in order to validate the behavior of the application and get some feedback on the virtual environment and game flow. We based our study on the standard Slater-Usoh-Steed (SUS) questionnaire (Slater et al., 1994) constituted of 6 questions evaluated with a 7 point Likert scale, 1 meaning "Not at all", 7 meaning "Completely". We translated the SUS questionaire in French as it was the native language of all the subjects in the experiment.

For this pilot study, we used an Oculus Quest 2 set up, in autonomous mode, in a large room in order to define a 10 m × 10 m physical space for the simulation.

Seven people (5 men, 1 woman, 1 non binary) performed the evaluation. Six people aged 18–24 years, and one, 25–34 years. All people were right-handed.

The user experience started at the service position in the historical court of Rennes. People were explained the serve rule, and then asked to perform services, up to 10 until succeeding one. After an automatic change of position in the court, they had then to return services until winning a chase. Finally, they had some time to visit the historical site using the teleportation mode.After the experience, they were invited to fill the SUS questionnaire. The results of the questionnaire are presented in Table 3.

This pilot study gives a positive indication on the feeling of presence of the users in the VR real tennis simulation, and thus on the quality of the proposed virtual environment, even if the quality of a VR experience does not only depends on the feeling of presence. According to informal feedback from the subjects of the pilot study, they enjoyed to discover this sport using VR. They liked the visual indications (area highlights as in Figure 10 bottom right) indicating where to serve. None of the subjects reported any discomfort related to the wearing of the helmet or the VR experience and some even extended the experience to try a match against the virtual opponent. Nevertheless, we cannot draw any more conclusions from this pilot study and more complete evaluations must be conducted to fully assess the effect of the VR application for real tennis preservation, promotion and training.

4.3 High-ranked players interview

We presented the simulation to two real tennis top level players, including the French number 1, World number 2 player, Lea Van Der Zwalmen (see Figure 15). They used the same set up than in the pilot study with a previous version of the VR application, with similar features.

They tested the application in the actual court of Fontainebleau, the virtual court of Fontainebleau being co-located with the real court. After having tested it, they both saw a real interest in this project, both for initiation and for high level training. They particularly insisted on the possibility to play when there is no court available, for example to train in their living room. In addition, this tool would allow them to work on a particular phase of the game and repeat it. For example, there are many different services that need to be practiced at their reception. They noted that the virtual simulator could be really helpful in practicing reading the trajectory of the ball. Another advantage they noted is the possibility to practice when there is no other player of their level available. Indeed, the low number of practitioners means that they do not always have an opponent of their level to train with, unlike our virtual opponent who is always available and tireless.

5 Discussion

The 3D model and the digitization of the building were used as a basis for a faithful 3D reconstruction of the building, realized through an interdisciplinary collaboration between archaeologists and computer scientists.The 3D reconstruction of the old building and court allowed us to represent all the missing architectural parts that were destroyed during the different reconfigurations of the building. In particular, we reconstructed the penthouses and the galleries characteristic of the real tennis courts. An external staircase and the openwork identified during the archaeological diagnosis were also integrated into the reconstruction.

The team modeled a player character and a crowd of spectators wearing costumes consistent with the 17th century, and integrated them into the VR simulation. We used tennis player animations obtained from a commercial package available

TABLE 3 Results of the Slater-Usoh-Steed (SUS) questionnaire.

Question	m	σ
Please rate your sense of being in the virtual environment	6.00	0.58
To what extent were there times during the experience when the virtual environment was the reality for you?	4.57	1.51
When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited?	4.29	1.60
During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere?	3.71	1.70
Consider your memory of being in the virtual environment 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	4.20	1.60
During the time of your experience, did you often think to yourself that you were actually in the virtual environment?	4.14	1.46

FIGURE 15
The female French number one testing the application on Oculus Quest 2, in the Fontainebleau court, France.

on the Unity asset store to animate the player character. These animations are believable enough for the current simulation, but will be insufficient for a high-level training environment. We plan to perform motion capture on high-level real tennis players to build a database of bio-fidelic animations.

An AI implemented in Unity manages the behavior of the opponent player character. The crowd is also animated and reacts to the game, creating a living environment for the experience. In the current version of the simulation, on the easiest difficulty level, the AI-controlled character targets the actual user, so that the user does not have to move quickly from one side of the court to the other, which can be difficult with an HMD. When the user returns the ball, the AI attempts to intercept it and throw it back to the real user.

As discussed in Section 3.3.2, the basic virtual player behavior allows a user to play in a limited physical space. However, the VR application is designed to be used in a large physical space with natural locomotion, as we aim for realistic sports training. Intermediate solutions for automatic locomotion can be considered, such as those already used in tennis games such as Wii Tennis (https://www.nintendo.fr/Jeux/Wii/Wii-Sports-283971.html). Such a locomotion design should improve the game for a large audience, but at the cost of less realism of the physical activity. For the cultural heritage part of the VR application, which involves visiting historical buildings, the teleportation mode implemented in the current VR application has been positively received by users.

The current version of virtual real tennis implements a simple real user versus virtual opponent mode. As mentioned before, it is easy to extend the simulation to display a match between two virtual opponents. This mode can be useful to implement tutorial modes with scripting of some phases of the game. We also plan to implement a collaborative version to propose a match between two users. The challenge in this case is to implement a coherent avatar to represent the real opponent, animated by the movements of the real opponent. Another challenge is to manage the latency problems induced by remote collaboration which can be particularly annoying in a sports environment. Another mode of collaboration consists in associating two real players in a doubles match. This is interesting to train the doubles player to perceive her/his partner's position and to improve her/his own positioning.

Among the different systems used to deploy the simulator, the wireless HMD seems to be the most practical because it allows free movement within a large area corresponding to almost half a court. The version in the CAVE installation is interesting because it allows the user to be present in the simulation with his own body, which is often important for sports simulation. However, a special feature of the game is that the ball can bounce off the roof of the penthouse as well as the wall behind it. In this case, the player loses visual contact with the ball due to the lack of a projection surface, which makes the game very difficult.

We experimented with co-located sessions in both courts, where the virtual courts were exactly superimposed on the real courts. This is interesting in the old Rennes building where only half of the court is accessible. This allows visitors to discover the history of the site and how it was used during its real tennis period. In this case, a virtual tour can also be easily offered within the VR application to present the different historical, social and cultural aspects of the site.

The results of the pilot study suggests a good behavior of the application, with an acceptable level of presence and no signs of cyber-sickness for the users. However, this should be completed by additional evaluations, e.g. using a Simulator Sickness Questionnaire (SSQ). The evaluation performed by two high-level players identified a number of strengths of the application to consider its use for sports training.

The VR application was presented to a general audience in a museum during the National Archaeology Days, an annual French science outreach event that aims to present archaeological findings and activities to the public. The simulator was presented in a small 4 m by 4 m area, using an HTC Vive Pro HMD, with a user's viewpoint display on a large monitor for the rest of the audience. Several dozen people experienced the simulator during the day and provided enthusiastic feedback, with some even asking if the app was commercialized. We are currently investigating a model to make the VR application readily available to help promote real tennis.

6 Conclusion

The real tennis VR simulation brings to life the functional context of a historical building, in addition to its architectural reconstruction. This simulation gives access to an intangible heritage, a sports game, in a fully didactic environment. This sport, very popular in the 17th century, has left many traces in the European culture and heritage. In particular, in France, several expressions of this game are still widely used in the current language.

The approach we have proposed, with a model allowing to identify the main elements to be taken into account in the virtual reconstruction of a TSG, can be instantiated for other TSG. This approach also allows us to clarify the different objectives that will drive the virtual simulation of a TSG. The first objective is heritage preservation. But we have shown that VR can go beyond that, with support for the dissemination and promotion of TSG if it is still possible, and even for high-level sports training if there is still a competition associated with TSG.

Future work will focus on several aspects corresponding to the three different objectives:

- Heritage preservation: we plan to integrate a scenario framework developed in our team to propose virtual visits of the site associated with short phases of initiation to the game. This framework initially developed for training applications (Claude et al., 2014) will make it possible to propose heritage-oriented visits

that museum curators will be able to personalize. This will be a new field of application for our framework with some challenges to meet its specificity.
- Real tennis promotion: we plan to investigate a wider distribution of the application. As HMDs are now increasingly available to a wide audience, we plan to target the delivery of a VR application compatible with HMDs that support the OpenXR framework.
- Real tennis training: This aspect will be explored through a new project in collaboration with the Comité National Français de Courte Paume to study the interest of the application of VR for high level players. In this project, we will identify the phases of the game where the simulation can help improve the players' performance, and we will evaluate the effects.

Another aspect to exploit is further exploration of the approach as applied to other TSGs. For this, we will benefit from existing collaborations on the study of XR environments to preserve and promote traditional dances, and from previous work in collaboration with archaeologists such as that presented in Gaugne et al. (2020) on the study of 15th century engraved tablets with traditional games inside.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RG led the design of the method and its instanciation. VG supervised the scientific work on the virtual reality part. J-BB wrote the archaeological part of the manuscript, under the supervision of EE, PD-M wrote the implementation part of the manuscript, under the supervision of RG and VG, RG wrote the methodological part of the manuscript, structured the manuscript, and led the discussion part. All authors contributed to manuscript revision, read, and approved the submitted version.

Funding

The work was partially funded by EUR Digisport under reference ANR-18-EURE-0022. EUR Digisport funded a Master internship grant for PD-M. The work was partially funded by Equipex + Continuum under reference ANR-21-ESRE-0030. Continuum funded the access to VR equipment, including the Immersia platform.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2022.922415/full#supplementary-material

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