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The Combination of Serious Gaming and Immersive Virtual Reality through the Constructivist Approach: An Application to Teaching Architecture

Irene Capecchi [1,*], Tommaso Borghini [2], Elena Barbierato [1], Andrea Guazzini [3], Elena Serritella [3], Tommaso Raimondi [3], Claudio Saragosa [2] and Iacopo Bernetti [1]

[1] Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, 4–50121 Florence, Italy
[2] Department of Architecture DIDA, University of Florence, 4–50121 Florence, Italy
[3] Department of Education, Languages, Intercultures, Literatures and Psychology (FORLILPSI), University of Florence, 4–50121 Florence, Italy
* Correspondence: irene.capecchi@unifi.it

Abstract: Immersive virtual reality (IVR) has proven to be a technology that can benefit the dissemination of cultural content. In 2019 was the five hundredth anniversary of the death of Leonardo Da Vinci. Given the few works that develop IVR technologies to explain the genius of the master, we decided to take advantage of the opportunity to learn about the master through the use of new technologies. To build an IVR application that aims to spread knowledge, it is necessary to define an educational paradigm and the type of application. Given the domain of the application and the need to convey complex/novel topics, the IVR application developed in this study is based on the constructivist framework and creates a serious game (SG). In order to explain Leonardo Da Vinci's thinking and design approach, we decided to focus on urban planning and architecture studies by explaining the projects envisioned by Leonardo da Vinci. This paper investigates whether an IVR-SG application maintains the fundamental characteristics underlying disclosure processes, such as immersivity and a sense of presence. Two secondary school classes experienced this by evaluating the application through a psychometric questionnaire. The results show that immersivity and a sense of presence were evaluated positively.

Keywords: immersive virtual reality; serious game; constructivism learning paradigms; Leonardo Da Vinci; urban and architecture planning

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1. Introduction

Immersive virtual reality (IVR) is a technology that, through a head-mounted display (HDM), allows users to immerse themselves in a computer-generated environment with a 360-degree view. The virtual environment (VE) can faithfully reproduce the real world and enhance the cognitive experience or create a virtual model that breaks down spatial and temporal constraints, in which the same physical laws of the real world do not necessarily apply. The serious game (SG) aims to educate or solve a problem in addition to its playful aspects; the use of game mechanics makes the disclosure experience more attractive and engaging.

Leonardo Da Vinci (1452–1519) is known primarily as an artist and a military engineer. However, he also approached architecture and urban planning, a field of an interdisciplinary nature in which Leonardo could best convey the essence of his thought: "Everything is connected to everything else". The projects that most highlight this multidisciplinary approach are: "La città ideale" (The Ideal City), "La città ideale dei Canali" (The Ideal City of Canals), and "La polita stalla" (The Clean Stable), which are all contained in Manuscript B, preserved at the Institut de France in Paris. The work of Leonardo da Vinci has been little

used in the development of IVR-SG applications. De Paolis et al. [1] created an augmented reality mobile application developed for an exhibition on Leonardo's inventions: it shows the general structure and working principles of some machines recognized in the pages of the *Codex Atlanticus*. The application is based on animated 3D models of the machines made through Blender, and it uses the AR Toolkit and Vuforia frameworks to superimpose virtual models on Leonardo's sketches, framed by the camera of mobile devices. Empler et al. [2] proposed a virtual reconstruction application of the vincian cenacle, creating a navigable 3D model. Inside the scene, the doors placed between the tapestries that come off the walls become an interface to enter and explore other areas of Leonardo's investigation.

The application allows students to immerse themselves in the Leonardo projects, live the space, and learn the mechanisms inside, using constructivism learning paradigms and SG design that make them personally involved and which break down complex tasks into smaller, simpler ones. The overall purpose of this study is to implement an IVR-SG application of Leonardo's drawings to disseminate and to introduce the design approach of Leonardo Da Vinci in secondary schools within a constructivist teaching framework. For this purpose, we assessed the application's immersion, sense of presence, and interactivity using a specific psychometric questionnaire.

The research questions are:

(1) Is it possible to use Leonardo da Vinci's notes to build exploratory and interactive IVR-SGs?
(2) How does the virtualization of Leonardo da Vinci's projects manage to combine the constructivist approach with serious games to disseminate Leonardo's thought in architecture and urbanism?
(3) Is the IVR-SG application of Leonardo's drawing designs immersive?
(4) Does the IVR-SG that recreates Leonardo da Vinci's projects enhance the students' sense of presence?
(5) Were the interactions offered within the world of Leonardo da Vinci perceived positively?

2. Theoretical Framework

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

2.1. IVR Features

There are many definitions in the literature for immersive VR, but they all agree on defining virtual reality by its inherent characteristics. Immersive VR has been defined as I3: Immersion–Interaction–Imagination [3]. It is important to define these three concepts.

- Immersion plays a crucial role in the creation of an experience perceived positively by users and can be declined according to two meanings [4].
    - Physical immersion represents the user's involvement within the VE and, more specifically, the degree to which physical reality is excluded from the user's perception [5].
    - The mental immersion sense of presence is the experience by the subject of being in one place or environment, even when physically located in another (Witmer & Singer, 1998).
- Interactivity can be defined as the degree to which a user can modify VE in real time [6].
- Imagination triggers the human mind's capacity to perceive and imagine non-existent things in a creative sense. In short, VR technology is well suited to conveying complex abstract concepts due to its visualization abilities [3].

2.2. Learning Paradigms

Learning methods can be distinguished between student-centered and teacher-centered methods [7]. In the former method, students are active participants in the learning process and not passive recipients, whereas, in the latter method, students absorb the knowledge that the teacher imparts. Constructivism is a learning paradigm that is part of the student-centered methods. Education for the constructivist paradigm is experimental and experiential; the subject constructs knowledge from their own experiences [8]. The constructivist approach envisions that the student in the environment is free to discover and implement problem-solving skills; in other words, knowledge is a dynamic quality built around discovery [8]. IVR technology is an excellent tool to apply in the constructivist approach because it provides users with an environment they can truly experience without imagining scenarios, and it can overcome the constraints associated with real-world situations.

2.3. Serious Game

To take full advantage of the immersive effect of VR, high learning rates must be achieved for the user to interact with the virtual environment. The use of games is the natural way to achieve high levels of interactivity. SGs are activities designed to entertain users in an environment where they can learn with a student-centered approach to instruction [9]. The use of games in learning is widely demonstrated in the literature because the games influence and increase the involvement and motivation of the student, who learns more consciously and permanently [10,11].

The results of the literature research show that games that combine information and interaction mechanisms are an excellent medium for experimentation in architecture and applied science [12,13]. Using IVR technologies such as visualization tools allows students to understand the spatial dimensions of the object, while as a drawing tool they serve students by implementing three-dimensional thinking and a better communication of the design [14]. A well-designed SG helps to develop the player's skills and allows him or her to gain attention because the game becomes innovative and the user is involved in the proposed interactions [15–18].

The development phases of IVR-SG are the following [11].

- Pre-design: In this phase, the goals and the general learning objectives are defined, with care given to the correctness of the educational content.
- Design: This is articulated in the construction of the storytelling, characterized by the freedom of action of the user, the experiential learning, and the progressive increase in the level of difficulty of the interactions.
- Evaluation: The application must be tested in two dimensions: knowledge acquisition and usability.

2.4. Perception of IVR Technologies in Education

There are only a few recent studies investigating the teachers' evaluation of IVR. Pioneering research conducted by Serin [18] in private schools in Iraq showed that the vast majority of teachers think that virtual reality encourages students to be active and facilitates information acquisition. The same authors also found that the use of IVR requires high concentration from students. These findings were confirmed by further work of Yildirim et al. [19], who analyzed through semi-structured interviews the opinions of seven teachers from different public schools in central Anatolia. According to the teachers, the use of IVR in the classroom allowed students to take virtual experiences. The teachers also noted negative aspects: the isolation of students in the virtual environment and the cost of the equipment. The teachers' opinion of IVR has also been investigated in school-based agricultural education in the US. Wells and Miler [20], through a reasoned action model found that teachers generally had favorable opinions about VR technology but also a significant degree of uncertainty about the technology and its uses. As with the previous research, cost was identified as the main barrier to the adoption of IVR in teaching. Finally, a recent study focused on the opinions of university engineering professors [21]. The results

confirm the positive evaluation of IVR as a teaching tool but show a lack of professors of specific professional training. Finally, Antón-Sancho et al. [22] found that digital natives say they are more proficient in the use of virtual reality and appreciate its technical and educational aspects more.

3. Methodology

This study is structured into four phases (Figure 1).

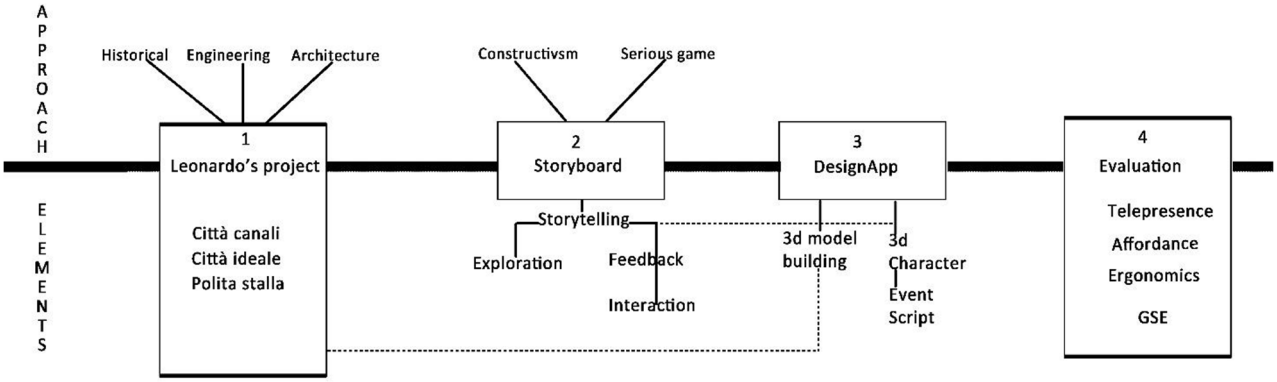

Figure 1. Workflow.

(1) The selection of Leonardo da Vinci's urban projects. The aim is to collect all the information about the single project and understand how the multidisciplinarity is declined.
(2) The definition of the storyboard. We combine the constructivism paradigms with the SG design of the IVR application in this design phase.
(3) The design and development of the app. In these application steps, we realize the 3D model and subsequently develop interactions.
(4) The evaluation. Here, we structure the questionnaire and administer it to the primary school classroom to detect the effectiveness of the application.

3.1. The Urban Projects of Leonardo da Vinci

Leonardo da Vinci's projects in urban architectural design are "Città ideale dei canali" (The Ideal City of Canals), "Città Ideale a Più Livelli" (The Ideal city on Several Levels), and "Polita stalla" (The Clean Stable). Leonardo develops a complex idea of a building/city, in which an architectural form supports the functions and aesthetics, creating a project where all these elements are balanced and collaborated. These projects were never realized; they were only imagined and drawn by Leonardo. To study them, it was necessary to start from the drawings and writings left by Leonardo da Vinci, now preserved in Manuscript B (1487–1490) at the Institute of France in Paris.

The phase of interpretation and translation of the notes into the 3D models was developed according to different approaches.

- The architectural approach is used to interpret and give truth to the drawings in the dimensions and statics of the object and understand the project's feasibility.
- The historical approach is used to contextualize the project and define the elements that Leonardo does not make explicit. In the descriptions that remain, there is only a description of the architecture, and there are no hints of the elements, materials, and objects; so, a historical filter is needed to avoid false history and to provide the user with a historically correct perception.
- The engineering approach is used to understand the dynamics of the operation within the project.

3.1.1. The Ideal City of Canals ("Città Idealdei Canali")

Leonardo describes a settlement located near a river to create a system of canals and locks to have water in the city and to use it to clean such a town. The Ideal City of Canals (Figure 2) is sketched with two identical and symmetrical buildings connected with a pedestrian bridge. The buildings have three floors: the first level is a basement, accessible from the river and useful to unload goods directly from the boats; the middle level is a round-arched porch with commercial buildings. On the last floors, there are only hints of the windows; they could perhaps be of the house of a nobleman, but no actual termination of the building is drawn. Leonardo emphasizes that the river must be characterized by a rapid water flow to avoid any proximity to stagnant water that pollutes the air. In addition, the canals can be used as an additional road that improves the system of communications and logistics.

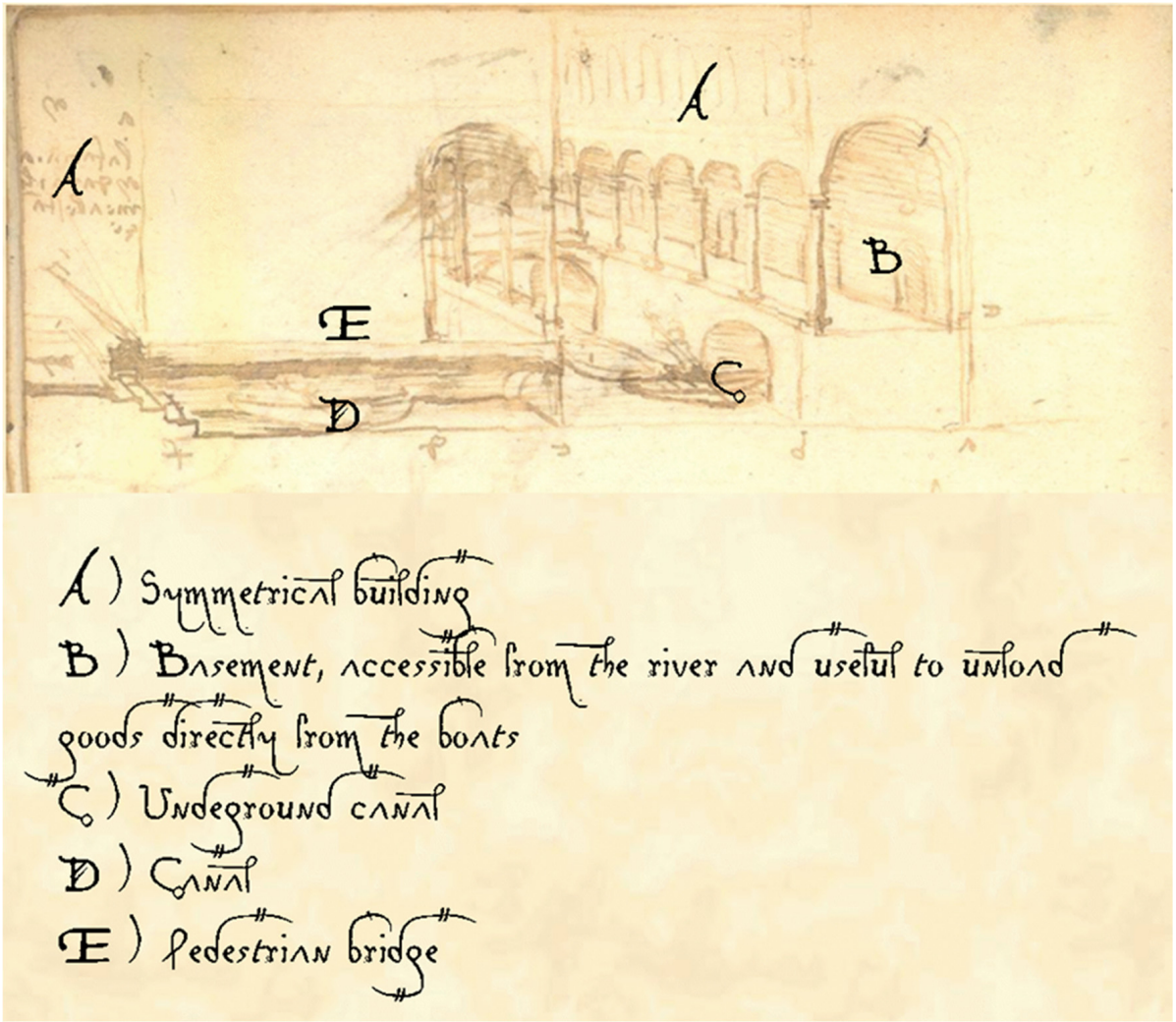

Figure 2. The Ideal City of Canals (our elaboration of original drawing).

3.1.2. The Ideal City on Several Levels ("Città Ideale a Più Livelli")

The cities of the late Middle Ages had a structure favorable to the spread of contagions and diseases: narrow and winding streets, high population density (especially in the poorest neighborhoods), open sewers, very precarious personal hygiene, and a large spread of mice and vermin. Leonardo proposed a new city structure that resolved the functional problem of the logistics and the poor sanitary and social conditions. The Ideal City reorders the town's road system on multiple levels, including roads for vehicles and people's activities on the lower level, while on upper-level are roads only "gentlemen" can pass (Figure 3).

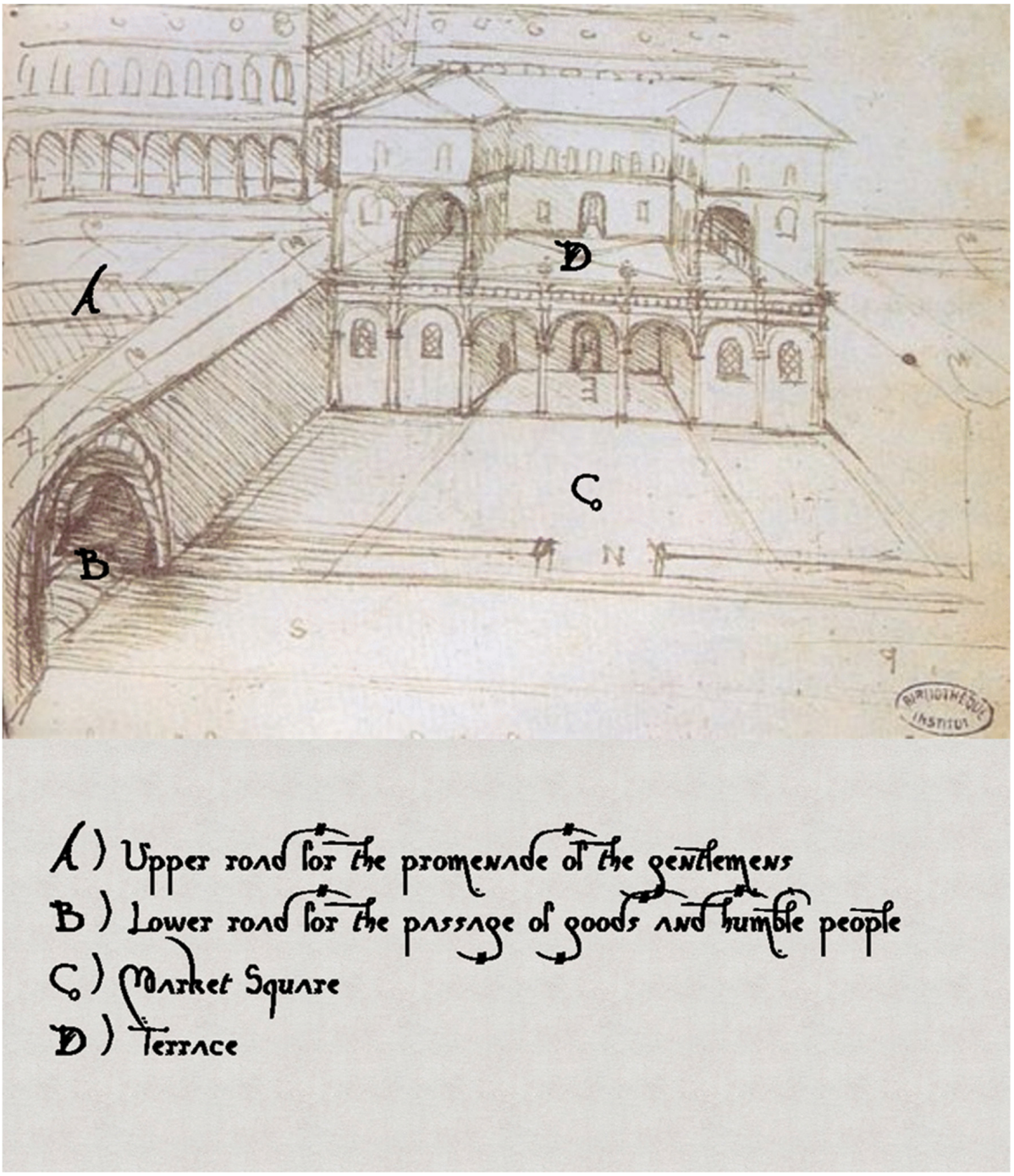

Figure 3. Ideal City on Several Levels (our elaboration of the original drawing).

3.1.3. The Clean Stable (Polita Stalla)

The Clean Stable is the most complex project because of the organization of the workflows and the architectural solution of the building that Leonardo proposed, which has different right and left sides. Leonardo's goal was to obtain a clean stable, and he divided the building into three floors, on each of which a specific activity took place. Leonardo proposed the design of a clean stable that allowed the welfare of both staff and animals inside by dividing and reorganizing the function. The workflow hypothesized by Leonardo follows a vertical path (Figure 4):

- The highest floor is divided into five naves; in the central nave, wider than the others, the hay is stored, while the two lateral ones are reserved for stablemates, and the most external ones are used for the distribution of rations to the animals.
- A large arched window on the back wall brings the straw from the ground floor. We find the designed machinery used to carry the straw up to the floor in the sketch.
- The middle floor is divided into three naves of the same dimension. The horses are on the sides, and the center is for the stablemates.
- The lower floor has been divided into two parallel tunnels, each of which ensures the outflow of equine manure.

Figure 4. The Clean Stable (our elaboration of the original drawing).

3.2. Storyboard

Learning Paradigms

The development of the IVR application was based on the constructivist learning paradigm and game-based learning, which allow each student to be free to explore the VE and build their own knowledge. One of the principles on which the project was based was that the student should and could freely interact with the environment to understand the functioning of the architectural and urban project by observing and experiencing it first-hand. The strategies with which we applied the constructivist approach are compatible with the SG and gamification approaches, and they are situated in learning, role playing, and problem solving.

The Ideal City of Canals (Figure 5) has mainly developed the part of situated learning where the students must observe the architectural structure and understand the role of the water. To do this, they can get on a boat and observe the architecture from multiple points of view. In this project, given the small size, the students are free to move anywhere, and there are no directions on how to proceed. They are free to choose whether to first get on the boat or whether to explore the buildings and vice versa.

In the Ideal City on Several Levels (Figure 5), the students, in addition to situated learning where they can walk freely in the city, must apply problem-solving mechanisms to understand their operations. Given the vastness of the environment, limitations were placed on movement to prevent going outside the areas of interest. The users are free to move wherever they want and can decide whether to visit the top or the bottom of the city first if they respect the boundaries.

In the Clean Stable (Figure 5), students also play a role play in addition to situated learning and problem solving. The students find themselves impersonating the stable master to understand the workflow hypothesized by Leonardo and how this has influenced the architectural project. In this case, the movement is more constrained and is also given by role playing and following the workflow. The users must first explore the lower floor, then go to the upper floor, and finally to the central part. In each area, however, the users are free to go wherever they want and must understand this operation for themselves.

3.3. Serious Game

The IVR application is based on the principles of gamification and SG: feedback, increasing difficultly, and clear goals.

The first part of the application included explaining what the students would see and do within the experience. Subsequently, a tutorial was developed to make the student autonomous in giving the necessary indications. The tutorial lets them become comfortable with the new way of moving and interacting with the VE and becoming familiar with the UI they would find in the game. As the game format requires, we defined different difficulty levels based on the project's complexity. This results in a different complexity of exploration and interaction in the VE; the order of complexity is as follows: Ideal City of Canals, Ideal City on Several Levels, and Clean Stable.

A fundamental element within the serious game is the presence of storytelling. In the developed platform, two different storytelling techniques have been used: in the introductory part, we talk about cinematic VR, while in the following phases there is the gaming storytelling; in the VE there are voice hot spots, marked by floating gold coins, which contain Leonardo da Vinci's explanations and suggestions (Figure 6).

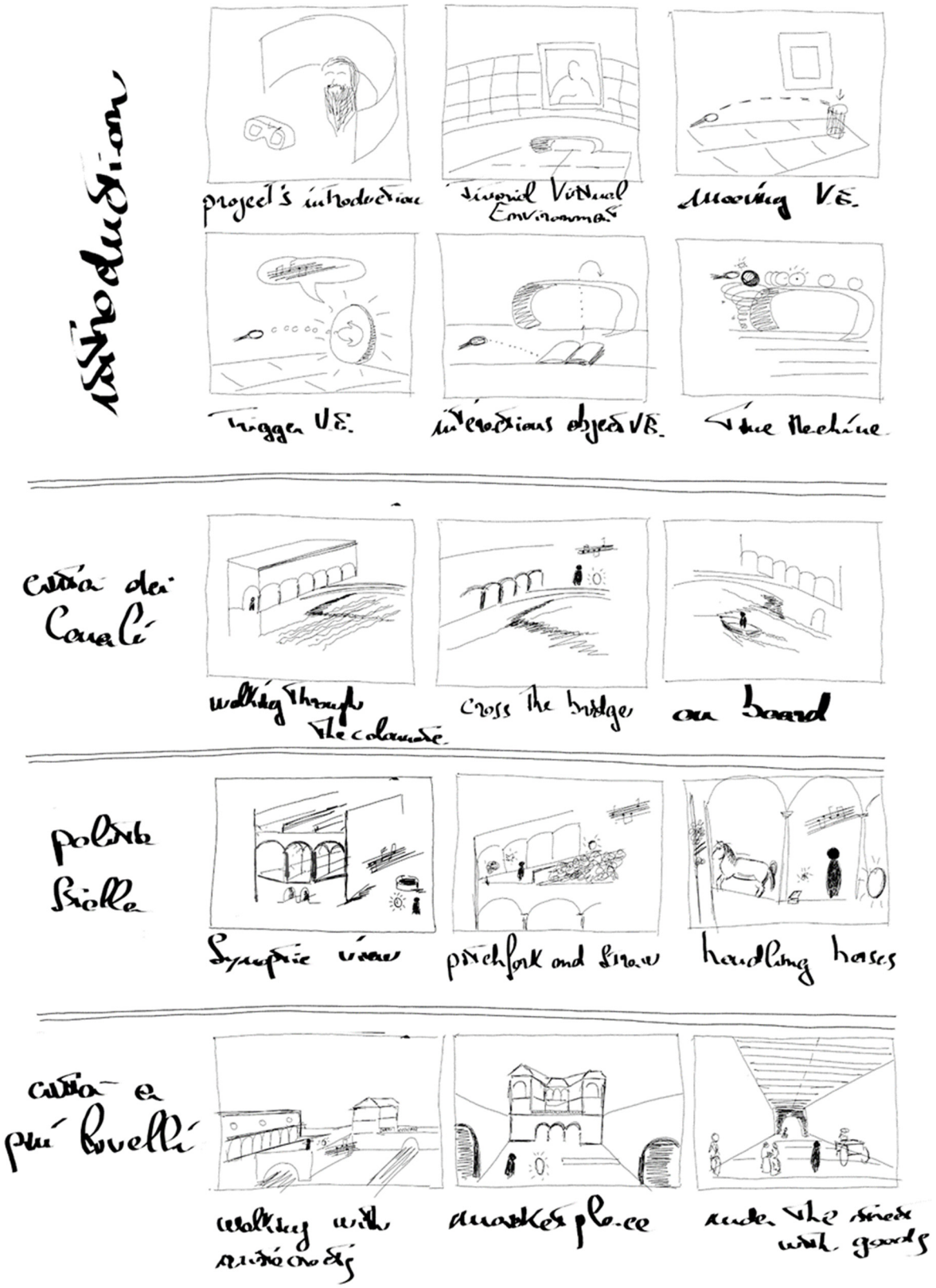

Figure 5. Storyboard.

Figure 6. Gold coin hotspot.

3.4. Design and Development of the App

The application is developed into seven scenes:

- In the first introductory video, Leonardo introduces his projects in the first person and explains what will happen next. In this case, we decided to create a 360-degree video that makes the users understand that they have a 360-degree view; so, the sketches of Leonardo's projects that appear are developed over the whole x-axis.
- In the second video, Cecilia, the woman with the ermine, introduces us to the IVR world.
- After these two videos, Cecilia explains how to move in the VE through some of the tasks.
- Finally, after acquiring these notions, the users are ready to begin their journey through time, immersing themselves in the first of the three projects: Ideal City of Canals; Ideal City on Several Levels; Clean Stable (Figure 7).

The application was developed using the following software: Audacity for voice recording, Blender for 3D model development, and Unity for IVR development. The characters and other contextual elements in the scenes were downloaded from sketchfab.com, and animated via mixamo.com. The video trailer (see Supplementary Material) shows the 3d models reconstruction and the functionality of the app.

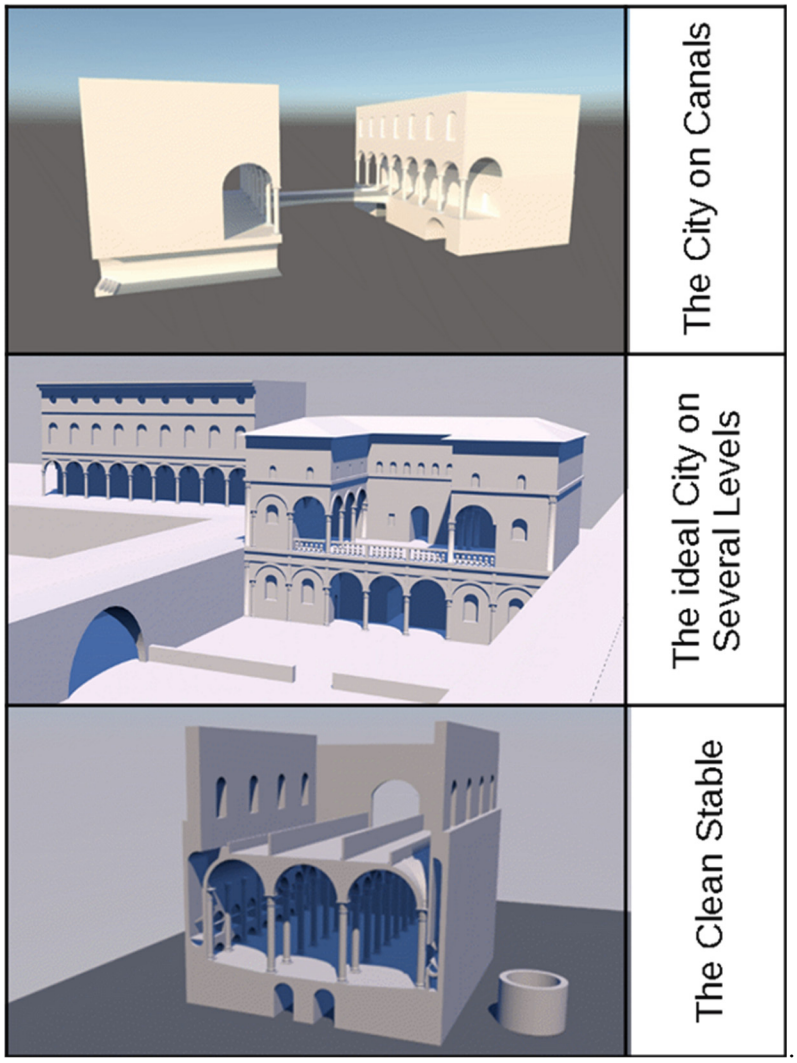

Figure 7. 3D models.

3.5. Evaluation

The evaluation phase of the application includes a first part in which we describe the approach with the student and the setting used to administer the questionnaire; the second part describes the psychometric test used and its four scales.

Participants

The questionnaire was administered to 35 secondary school students (17 boys and 18 girls) ranging from 14 to 16 years old. In the preparation phase of the IVR experience, we explained to all the children what they would see and the sequence of the scenes (Video 360-Tutorial-Leonardo Projects), always leaving the task of exploring the VE (Figure 8), in line with the principles of constructivism. Through multimedia aids, we explained the meaning of the gaming elements that the users would encounter on their journey. We then explained how to move and interact within the virtual environment via the controller. The IVR experience was performed by the students wearing an HTC VIVE PRO in a 4 × 4 sized environment. At the end of the experience, the boys filled out the questionnaire via a tablet (See Supplementary Material).

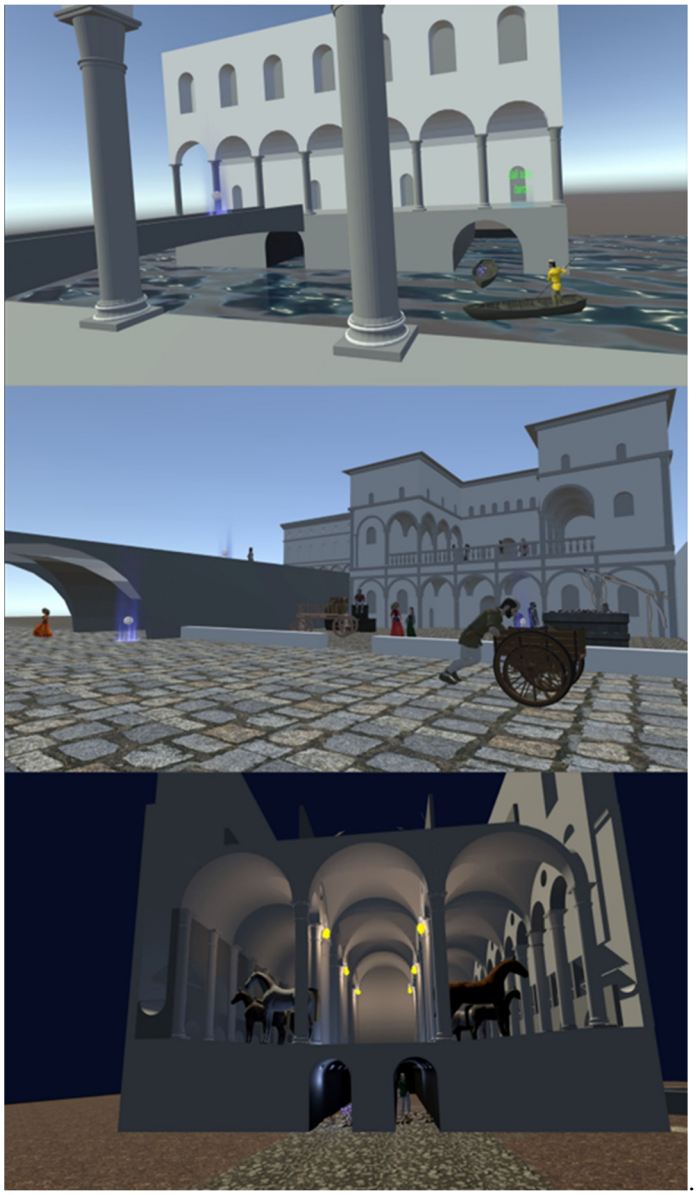

Figure 8. Administration process.

To verify that the developed application, despite the game elements present, was effective as a learning tool, a psychometric questionnaire was submitted to the students to evaluate the elements that ensure learning, such as the sense of presence, immersion, and interactivity. The questionnaire administered consists of four different sections, each corresponding to a precise scale: telepresence, affordance, cognitive and perceptive ergonomic, and general self-efficacy.

Telepresence

The IVR's sense of presence affects the quality of student learning, which is why Steuer in 1992 developed the concept of "telepresence". Telepresence is defined as "the sense of presence in a mediated environment" [6]. A high degree of telepresence testifies to a mediated experience, as with an actual direct experience. In the educational field, a variety of studies have reported how telepresence, immersion, and flow are essential elements of the player experience that can simulate authentic problem-solving tasks that combine instruction, learning, and assessment [23,24]. For assessing telepresence, this research used the 7-item scale developed by Klein [25].

Affordance

The concept of affordance was introduced to understand the level of immersion in the VE environment [26]. In an IVR experience, users actively engage with what is happening rather than being passive recipients [27]. Therefore, when designing VEs, designers should take advantage of the opportunities provided by the technology and be informed about their affordances [28]. Affordance on VR is divided into technological affordance (property/significant) and the affective affordance of the technological property perceived by users. For the present study, it was developed on an ad hoc scale to assess the perceived affordance of the game. The scale had five items and it used a 5-point Likert scale, asking the users if it was simple or intuitive to move in the space or interact with the objects in the environment. Focus groups were made to identify the preliminary items and to select those which were more sensitive and reliable, based on their construct validity, reliability, and sensitiveness.

Cognitive and perceptive ergonomics

Ergonomics is defined as the balancing of the workload and the workforce in the best possible way to protect the health of the individual [29]. Cognitive ergonomics aims to ensure the compatibility required in the functioning of artifact–human systems concerning the complex and uncertain (cognitive) interrelationships between system users, machines, and environments [30]. For this reason, the role of ergonomics in our project is based on developing improved virtual environment interfaces and enabling better use of technology by specifying user needs and requirements and developing evaluation methodologies.

In the literature, there is no valid scale to measure these constructs; for this reason, we developed an ad hoc scale for our project, starting from a focus group to identify the items; then, we started to select the suitable articles in terms of the most sensitive and reliable, based on their construct validity, reliability, and sensitiveness.

GSE

The GSE scale is a ten-item scale that has been translated into 22 languages, including Italian, from the original German version by Schwarzer and Jerusalem [31]. It assesses the strength of an individual's belief in his or her ability to respond and adapt to new or difficult situations and to cope with any obstacle.

The GSE scale is positively related to emotion, optimism, and job satisfaction, while it is negatively related to states of depression, stress, burnout, and anxiety. An effective educational game should include appropriate challenges that can make students self-efficient [32]. In addition, a variety of studies have reported that game-based learning can enhance students' general self-efficacy [33,34].

4. Results

Once the survey data were collected, they were analyzed through the software for statistics R studio version 1.1.4. The data were analyzed using descriptive statistics indices to understand the distribution of the ratings. In general terms, for each user, we calculated the total average of the individual scales and then analyzed the distribution. We can observe that among the four scales, GSE is the one with the highest score below five and the lowest below two. The scales with the highest average scores are telepresence and cognitive-perceptual ergonomics. Telepresence and ergonomics are the scales related to immersion and a sense of presence, showing that the user felt immersed inside the virtual environment and was not disturbed by it. To make the results more readable, we organized them according to the four scales present in the questionnaire: telepresence, affordance, ergonomics, and GSE (The questionnaire, with complete reliability and validity data, is available in the Supplementary Materials).

In sum (see Table 1 and Figure 9), the mean of each scale was higher than 3.50 (in a 5-point Likert scale); so, the students' felt immersed enough in the Virtual Leonardo Da Vinci VE (4.04 on average), and they judged the IVR app with a good affordance (3.79 on average) and excellent perceptive and cognitive ergonomic characteristics (4.09 on average). Furthermore, the students considered themselves adequately self-efficient (3.59 on average).

Table 1. Descriptive statistics of the four scales used.

	Telepresence	Affordance	Perceptive and Cognitive Ergonomics	General Self-Efficacy
Mean	4.04	3.79	4.09	3.59
Median	4.14	3.80	4.14	3.70
Mode	4.00	3.60	4.29	3.50
Standard Deviation	0.51	0.64	0.56	0.58
Variance	0.26	0.41	0.32	0.33
Asymmetry	−0.97	0.15	−0.47	−1.26
Kurtosis	1.11	−0.97	−0.10	2.20
Minimum	2.57	2.80	2.71	1.70
Maximum	4.86	5.00	5.00	4.50

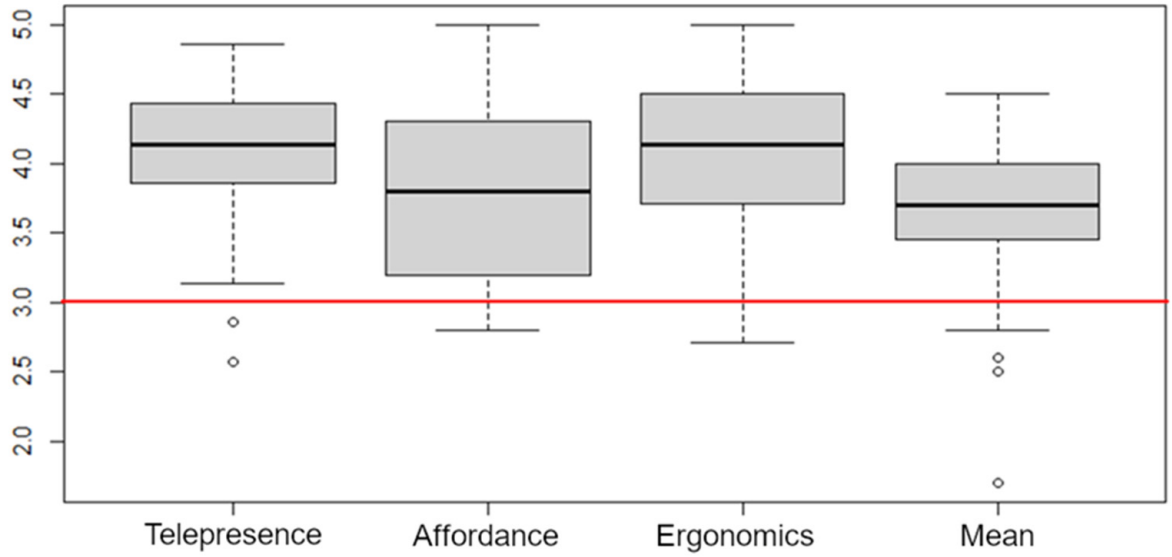

Figure 9. Frequency distributions of the values of the analyzed dimensions (the red line shows the acceptability of the achieved level).

As can be seen from Table 1, all of the telepresence metrics items have positive mean, median, and mode values, i.e., they are all above the neutral value of 3 (neither agree nor disagree). This highlights that the virtualization of Leonardo da Vinci's world allows for a high level of immersion and a strong sense of presence on the part of the students. To analyze the individual items, it is interesting to note that the highest mean value with a fairly small standard deviation is found in item 3. Item 3 shows how the students were mentally immersed in the VE. Values higher than four were also found for topic 1, "While using the application, I felt like I was in the entire world created by the computer", for topic 6, "I forgot what was in my immediate vicinity while doing the computer exercise", and for topic 7, "When the computer exercise ended, I felt as if I had returned to the real world after a trip". Overall, the results thus demonstrate that the dimensions of telepresence (see Witmer and Singer 1998) most perceived by users are those of involvement (distraction factor, topics 3, 6, and 7) and realism (topic 1).

All the items related to the affordance of exploration and interaction (topics 2, 3, 4, and 5) have values above four and demonstrate that the VR application was developed with a user-friendly design and interaction mechanisms. A significant result is the one related to the unfamiliarity of the respondents with the tool used and the investigating of the familiarity with the virtual reality headset (topic 1). The fact that the sample being analyzed was not familiar with the tool further corroborates the effectiveness of the proposed interactions, highlighting that positivity does not come from having already tried it.

Ergonomics comprises seven items that can be evaluated with a 5-point Likert scale (not at all–very much). Before proceeding with the data analysis, it was necessary to pre-process the data. In items 2, 3, 5, and 7, the question was asked negatively concerning the other items; therefore, the scores' complement to the maximum value (5) was calculated. This resulted in a consistent rating for all the items. All of the various items had scores between 3 and 4. This scale positively evaluates the training portion provided initially and during the Leonardo Da Vinci SG. Item 6 evaluates Leonardo's voice to explain the concepts of architecture and urbanism, and as can be seen from Table 1 and Supplementary Material the summary indices are positive.

The dimensions of the GSE were rated very homogeneously and neutrally by all the respondents, with mean values ranging from a low of 3.31 (items 4 and 8) to a high of 3.97 (items 1 and 6) and a consistent median of 4. This scale, therefore, did not provide useful information to characterize the quality of the application.

As for the affordance results of the IVR application (Figure 10), we can notice that all of the five items, except the first that assesses the familiarity with the virtual reality headset, exceeded the threshold of acceptability of 3. All the items related to the affordance of exploration and interaction (experience, movement, and immersion) had values above 4 and demonstrate that the VR application was developed with a user-friendly design and interaction mechanisms. The fact that the sample analyzed was not familiar with the VR tool further corroborates the effectiveness of the proposed interactions, highlighting that positivity does not come from having already tried it.

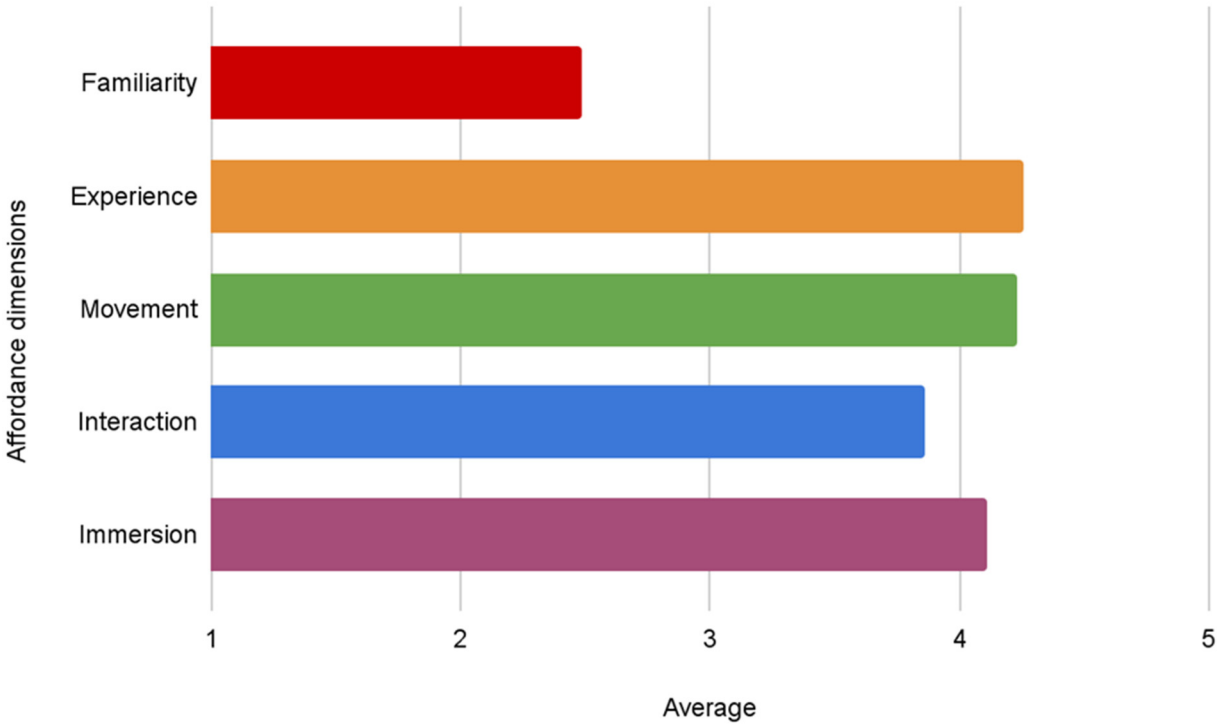

Figure 10. The item averages of the affordance scale.

Before showing the results of the ergonomic scale (Figure 11), it must be underlined that item 2, "Difficulty of adaptation"; item 3, "Disorder due to immersion"; item 5, "Immersion fatigue"; and item 7, "Disorientation" are inverted items. It means that for these items the lower the averages, the better the ergonomics. The other items (1, 4, and 6) scored between 3 and 4, indicating that the students had a very good perception of the understandability, agreeableness, and ease of use of the VR tool. The overall results prove that the Leonardo Da Vinci serious game had very good ergonomics.

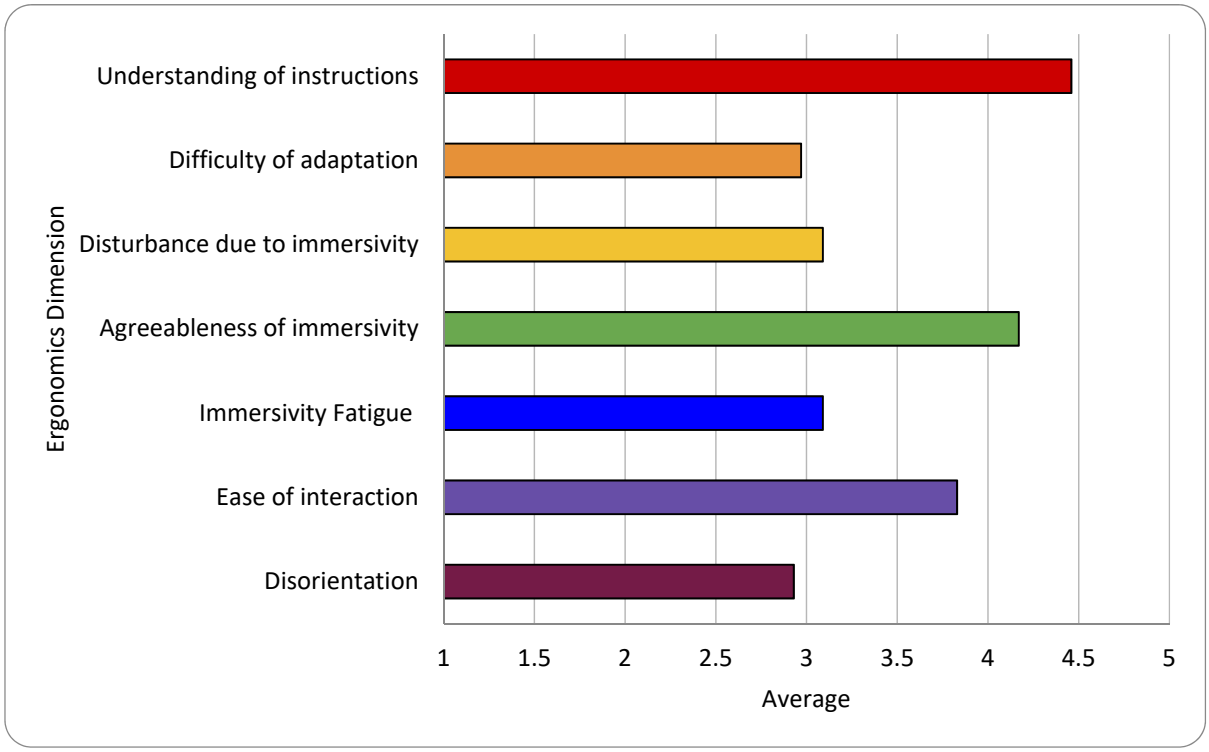

Figure 11. The item averages of the ergonomic scale.

As shown in Table 2, there was a positive correlation between general self-efficacy and telepresence with a Pearson's correlation coefficient of r = 0.346 (p = 0.05) and a strong positive correlation between ergonomics (cognitive and perceptive) and affordance (r = 0.487; p = 0.01). The other correlations were not a statistically significant analysis of the psychological dimensions measured in the survey.

Table 2. As shown in Table 2, only four of the psychological variables measured in the survey correlate.

	Telepresence	Affordance	Ergonomics	General Self-Efficacy
Telepresence	1	0.007 (0.970)	0.105 (0.548)	0.346 * (0.041)
Affordance		1	0.487 ** (0.003)	−0.088 (0.613)
Ergonomic			1	−0.132 (0.450)

Two-tailed significance is reported in parentheses. * The correlation is significant at the 0.05 level (two-tailed). ** The correlation is significant at the 0.01 level (two-tailed).

5. Discussion

Starting from Leonardo Da Vinci's drawings and writings, we could recreate three-dimensional models and make them accessible and visitable in the first person through an IVR app.

This application combined the approach of the constructive paradigm with the design of the serious game and managed to create an exploratory and interactive IVR-SG. The complexity was to combine and balance the game mechanics, including elements of guidance for the user as feedback and instructions, with the freedom of exploration characteristic of the constructivist approach. This was made possible by delineating the concept of affordance in the VE. The application was perceived by users as strongly immersive and created a high sense of presence. The students positively perceived the interactions in both the user mechanics and the interface. Thanks to the initial training, the students immediately recognized what the interactions were and how to interact with them. This element allowed them not to feel uncomfortable inside the VE.

In this kind of application, two key factors are usually considered: user satisfaction and learning indicators; immersion and usability factors are rarely considered useful to understanding the validity of the IVR application (quote). For this reason, we decided to create a psychometric questionnaire that implements specific scales of usability and immersivity.

Telepresence and ergonomics are the scales related to immersion and the sense of presence, showing that the user felt immersed inside the virtual environment and was not disturbed by it. From the statistical analysis carried out on the data that emerged after the use of the Leonardo Da Vinci IVR-SG application by the sample, we can see how the measurements of immersion, affordance, and ergonomics push the application to achieve the initial objectives set. In fact, the averages of the scores of these scales turned out to be quite high, confirming the validity of the proposed solution.

In addition, as shown by the high correlation between the general self-efficacy scale and telepresence, the GSE must be kept in consideration when it comes to designing projects based on virtual environments.

These considerations are confirmed by the literature. Consistently, previous research on immersion and user studies [35] shows that affordance, telepresence, and ergonomics are the primary constructs for learning via IVR-SGs. In accordance with our results, Chan et al. [36], experimenting with IVR-SGs for safety in chemical laboratories, found that applications with more advanced technological features can provide a high level of immersion and reduce symptoms of simulator sickness. The high importance of immersivity in cognitive acquisition in IVR-SGs was also noted by Luigini and Basso [37] in an application on learning traditional cultural heritage practices. The correlation between the dimensions of affordance and those of ergonomics is also found in the literature [38,39].

6. Conclusions

The IVR application developed in this study was based on the constructivist framework and created a serious game (SG) aimed at explaining Leonardo Da Vinci's design thinking and approach. Two secondary school classes tested it by evaluating the application through a psychometric questionnaire. The results show that immersivity and the sense of presence were positively evaluated. Thus, we can say that the IVR-SG approach was successful because, through the gamification of procedures and the use of game design techniques, it enabled the IVR app to achieve high levels of telepresence, affordance, and perceptual and cognitive ergonomics. Precisely because of this aspect and because the work was developed for dissemination purposes, we did not set up a procedure for verifying the learning objectives. Moreover, given the cost of the equipment, the sample remained particularly small.

The results of this application could be extended to other contexts besides Leonardo da Vinci's projects, such as in the area of heritage site planning by virtualizing the complex relationships between context of use, technological solutions, and learning effectiveness.

In order to solve one of the weaknesses of SGs-IVRs [19,20], a future development of the research will be to set up sampling with specific questionnaires administered to two samples of students: one with learning through traditional methods, the other with learning through VR-SG. Further development will be to implement surveys with greater numbers, especially thanks to the new low-cost VR and standalone technologies (Meta quest2).

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/educsci12080536/s1, Questionnaire form; Complete reliability and validity data; Application's Video trailer.

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