AUGMENTED GEOMETRY IN UNIVERSITY EDUCATION

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AUGMENTED GEOMETRY IN UNIVERSITY EDUCATION

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Abstract

Drawing is a primary subject in university. Students learn tools and methods for representing any shape in the plane and space to deal with projects related to architecture, engineering, and design fields. The research aims to develop an innovative, interactive, inclusive, and engaging "augmented" didactic method to simplify cognitive processes in the geometric teaching domain. Augmented Reality (AR) introduction in the educational path determines a clear advancement in knowledge by merging the representation of two-dimensional and three-dimensional objects in both plane and space. The proposal of a method based on AR visualization by different levels of interaction allows the student to understand shapes, and tailor their learning experience to their individual needs. The AR experience is tested in specific Representation courses at Sapienza University. However, it will be scalable to any field in which 3D representation is a vehicle for understanding content or functional processes.

Keywords: Augmented Reality, Geometric Shapes, Interactive representations, Engaging visualization.

1 INTRODUCTION

The research topic is related to the Augmented Digital Representation of geometric shapes applied in teaching geometric drawing at university and secondary schools. It is a vast domain resulting from centuries of evolution in transmitting theoretical knowledge for reading and understanding the built environment. The research for new interactive, inclusive, and engaging didactic methods within this topic has a profound national and international relevance.

The teaching of drawing is primary for all disciplines and work activities related to the subjects of Architecture, Civil Engineering, and Design. Courses that use geometric shapes to understand existing reality are numerous in Italy. At Sapienza University, drawing courses are in 14 different degree courses (Bachelor and M.Sc. levels) for 220 university credits. This scenario, reported on a national scale, gives a preview of the potential users of new methods and applications in the specific field. Besides, there are many drawing courses in most high schools' curricula. In general, teaching drawing is essential at multiple levels of education.

Drawing courses today combines traditional teaching methods, based on theory and practice by hand, with digital tools. Over the past two decades, the evolution of this teaching has shown significant changes in both content and learning approaches, thanks to the introduction of digital drawing and representation methodologies. The balance between manual and digital approaches guarantees the correct understanding of the construction and representation of the geometries on the plane and in space. It happens according to various methods, respecting learning time and expertise formation.

This integration is also a crucial topic for the European Community, emphasizing the importance of using ICT in the various school grades. In particular, the focus is placed on digital competencies as essential for developing problem-solving and analytical thinking skills [1]. The massive use of ICT technologies in education meets, on the one hand, the increasing ability of students in the use and management of digital data and m-learning [2] at universities [3] and high schools [4] levels. On the other hand, it supplies an answer to the increasing need to transmit dynamic content within multi-platform information flows. The recent pandemic emergency has made the use of ICT on a global scale cogent, focusing a great deal of attention on remote learning and ed-tech [5] and blended learning [6].

Applying innovative methodologies based on Augmented Reality [7] can play a fundamental role in implementing and developing specific teaching methods. The introduction of AR in drawing courses makes it possible to enrich a well-established discipline with a dynamic and interactive teaching component, facilitating specific cognitive processes. The research described here, therefore, proposes an education path of Descriptive Geometry based on the mixed-use of traditional and digital representation through AR, evaluating the advantages of geometry generation and representation in

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space. The experimental phase is being applied in courses at Sapienza University, planning a near future application at the high school level.

2 STATE OF THE ART

The topics developed by the project are well-established at a scientific level. Many types of research are published in the leading journals in the EdTech sector. Given the vastness of the domain, only two specific aspects are deepened within the state of the art.

The first topic concerns the use of AR for teaching geometry and architecture. The geometric-graphic training (GGT) for students at a university is fundamental for preparing future graduates for design and development activities [8]. At the level of AR, a pioneering project is the 'Construct3D' [9], developed from 1999 to 2008 by the TU Vienna and focused on the interactive and collaborative generation of surfaces, solids, and intersections in real-time through AR and VR. A second example is the 'HyperCAL3D' project, designed to encourage and support the teaching of descriptive geometry in the classroom and point out certain levels of interactivity that can be implemented through user feedback [10]. In the university teaching on architectural representation, some research has highlighted the motivational role of using mobile devices with AR and the difficulty in generating content [11][12]. Other research instead focuses on using AR for teaching descriptive geometry constrained by specific 3D modeling software, showing the potential of constructing personalized design paths [12]. Finally, some experiments focus on teaching geometry in secondary schools through AR, highlighting the positive impact of other web applications [13]. Overall, these examples outline a scenario of the research space in this area and the potential of using AR via mobile for teaching geometry and architecture [14][15].

The second aspect concerns using Augmented Reality to increase the interaction between the user and the 3D model through real-time transformations [16]. In this direction, the literature review proposed by [17] analyses many works in different learning contexts (i.e., schools, museums, and parks), highlighting the pros and cons of using AR. While, on the one hand, the study highlights the vast potential of AR in simulating immersive learning experiences [18], critical technological limitations still hinder its mass diffusion in the educational field. Among the most relevant are mobile technologies and space analysis problems [19]. Indeed, current systems still lack specific hardware to produce real-time depth information about the surrounding three-dimensional space [20], which is necessary not only for the correct visualization and positioning of a 3D model but also for the dynamic projection of its shadow [21][22]. These bottlenecks make the definition of high-level AR applications very complex: minor errors in positioning the 3D model or in managing the interaction between light and shadow are enough to generate a lack of coordination with reality and a significant loss of quality in terms of interface usability. The RAD-AR (Representing Active Didactic by Augmented Reality) project, started in 2020, suggests some developments in UI interaction with basic 3D primitives to test some of these bottlenecks, opening up a new way of transferring knowledge and learning the contents of descriptive geometry.

3 EDUCATIONAL SCENARIO

Most AR educational projects are devoted to different levels of education compared to university, where there are few experiments on basic subjects such as geometry teaching. The introduction of AR does not lead to an upheaval of the teaching system as much as its innovation, fitting into this alternation between manual and digital drawing through a new proposal for understanding geometry in space.

The orthogonal projection representation of graphic primitives in space represents the first real cognitive obstacle for any drawing student. This difficulty stems from the fact that such representations result from a process of abstraction, which generates flat geometries. Furthermore, course experience has shown that students can better understand perspective projections, which are more similar to the human visual system than parallel projections. On the other hand, the geometric construction of parallel projections is more straightforward from an executive point of view and is the most commonly used representation system in architecture.

In this scenario, the introduction of AR through an APP may facilitate understanding the transition from plane to space. AR's ability to translate orthogonal projections into perspective views (and vice versa) in real-time makes it possible to merge the two methods of representation, which are opposite from both an executive and cognitive point of view while preserving their meaning (Fig. 1). The use of this visualization method involves the student more closely in the process of creating and understanding the shape, introducing a personalization of the learning path through the choice of the point of view useful for learning.

In this step, it is crucial to emphasize how important it is to preserve the teaching of hand drawing in this experimentation to guarantee execution times consistent with the learning of projective genesis.

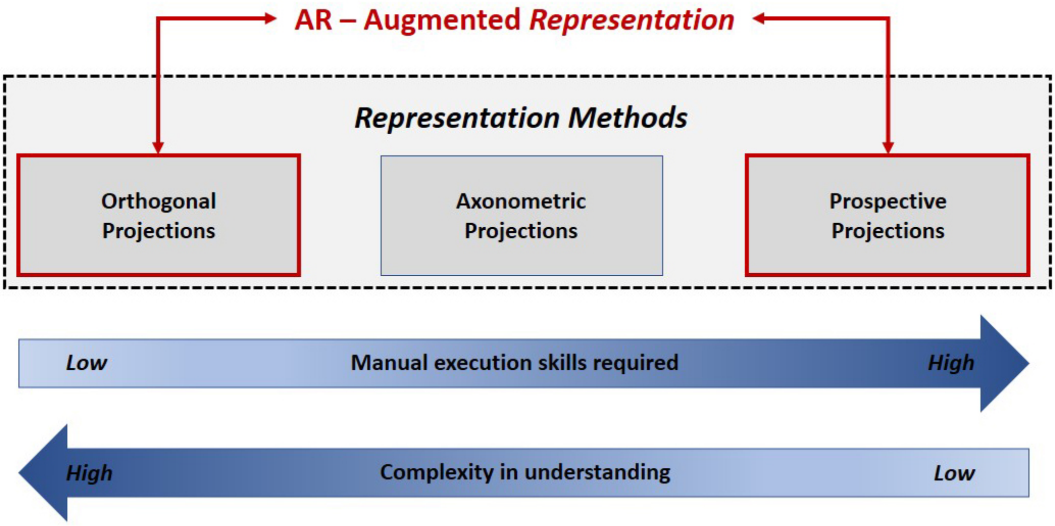

Figure 1. Connection diagram between the main methods of representation, the manual skills required, and the complexity of understanding the processes.

4 METHODOLOGY

The methodology developed over the two years of the RAD-AR project involved different phases of the design and verification of the APP. Specifically, after an initial user interface (UI) design phase, two passages of APP definition (α-test and β-test versions) and internal verification were alternated. A third external verification with university students was then planned. This last phase was preceded by the definition of an experimentation protocol aimed at a cyclic verification of the gaps and potentialities in the different classroom experiences, varying the audience of students, the level of education, and the content, to gather most of the helpful information for a second level of project development.

4.1 Application concept

From the point of view of UI design, the process started with some essential preconditions. On the one hand, the introduction of a principal trihedron within which to interact with different geometric primitives to intuitively understand the relationship between the position of the primitives in space and their projection on the principal planes (Fig. 2).

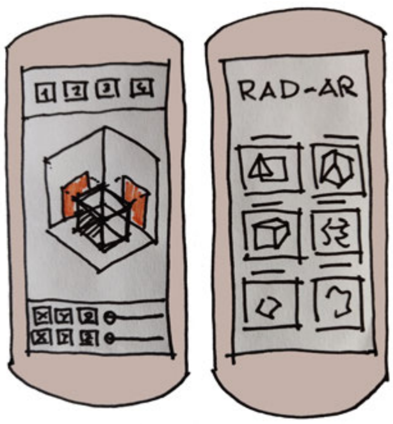

Figure 2. RAD-AR APP user interface design sketches.

On the other hand, the possibility of exploring the concept of geometric transformation (translation, rotation, and scaling) of primitives concerning their projection onto planes. Finally, the possibility of introducing at least two primitives in the same virtual environment, beginning to explore the relationships between the different fundamental geometric entities.

4.2 App definition

Rad-AR APP was developed using Unreal Engine\footnote {www.unrealengine.com}, and the interaction was created using both Blueprints and C++. The final output was an Android application running on compatible AR-enabled devices. Unreal Engine makes the application suitable for future porting to IOS devices straightforward. Moreover, the application has been designed with a modular framework allowing the developers to add more content (such as new 3D models) very quickly. The user interface went through many iterations based on users' feedback. In Fig. 3a, one of the early versions of the game can be observed, whereas, in Fig 3b, the same interface is at a later stage during development.

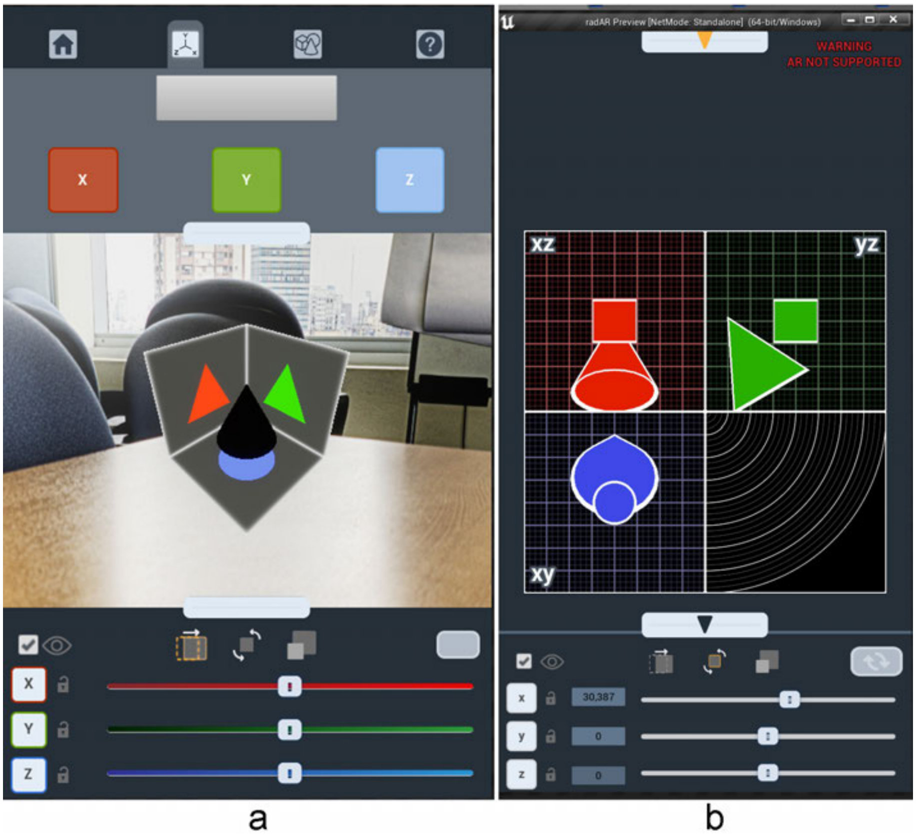

Figure 3. Different development steps of the APP (UI and contents)

All user interfaces share a similar visual style in typography and color. The interactivity allows different types of input methods. For instance, the lower interface controls the current 3D model using sliders, touch, or direct input-text fields. Other menus allow users to traverse through various interface areas using tabs, such as in the top menu. RAD-AR is an app that allows users to manage many parameters regarding different 3D models (Fig. 4). We arrive at nine editable parameters per single object. For instance, to change the object's position, at least three sliders were needed, one for each axis, three more parameters for scaling, and another three for rotation. The main challenge during the development of the RAD-AD interface was to make it both readable and usable, ensuring complete user control, the convenience of use, and ease of visualization of the model and its projections. To achieve this, we opted for two pop-up menus at the screen's top and bottom. The top menu contains all the features that do not require continuous use, such as accessing the model library, accessing the tutorial, or changing display modes. On the other hand, the bottom menu contains all the sliders and buttons helpful in selecting the 3D object and feature (scale, position, rotation) to be modified. Closing both pop-up menus lets, you view the 3D object and its projections clearly and cleanly. For additional viewing convenience, we have added a 2D mode in which only the projections of the object are shown.

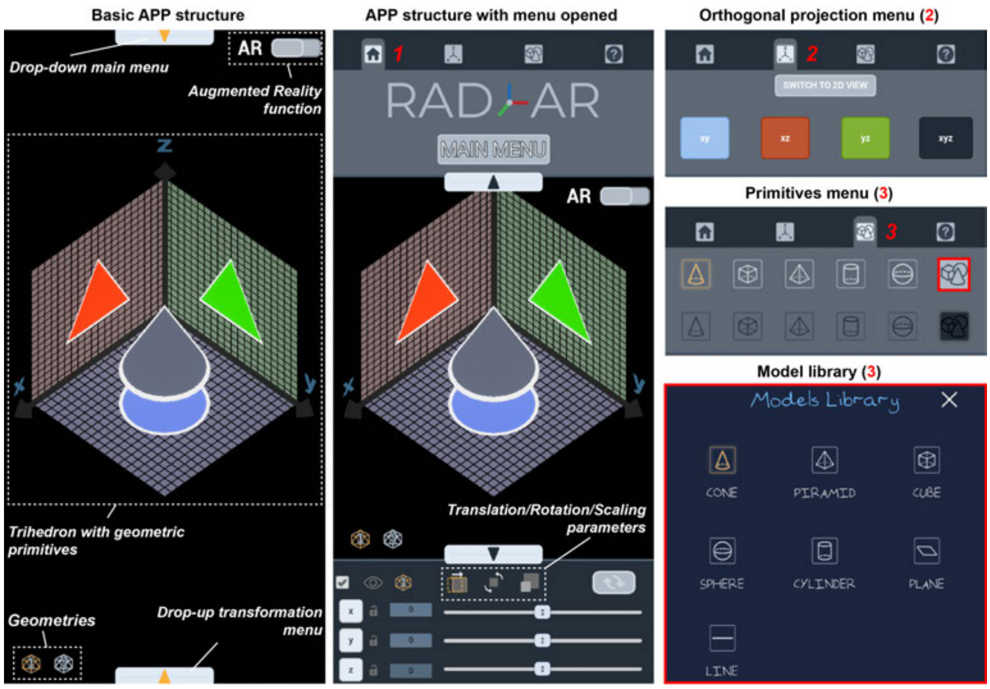

Figure 4. Main UI menus of the RAD-AR APP.

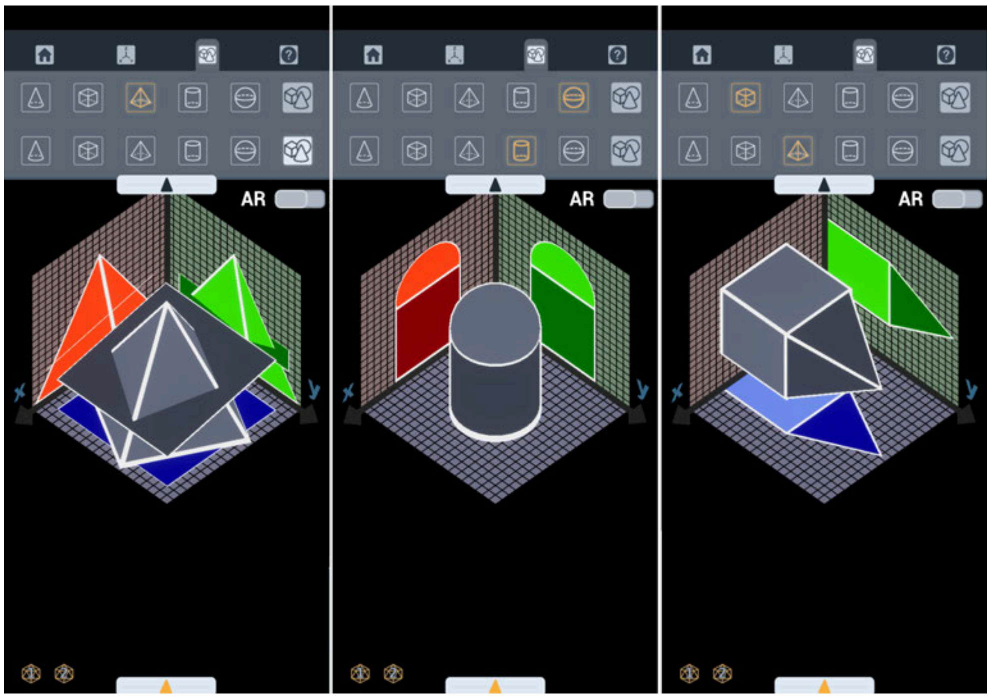

Figure 5. Examples of intersection and composition of two graphical primitives in trihedron space.

Projections of the 3D model are generated in real-time by three virtual textures. Three virtual cameras, positioned in front of the three planes, continuously monitor the scene, including the position of the 3D model. They generated a texture projected on a grid through a shader and applied it to the corresponding plane. The possibility of inserting and managing two graphic primitives contemporarily by retrieving them from a dedicated and implementable library has also been provided (Fig. 5). Finally, in the AR visualization mode, the dual markerless and marker capability of either displaying the model on every plane or recognizing a specific marker has been introduced. In both cases, the UI is integrated with a slider that allows scaling of the model display so that it can be optimized and not constrained by the target size (Fig. 6).

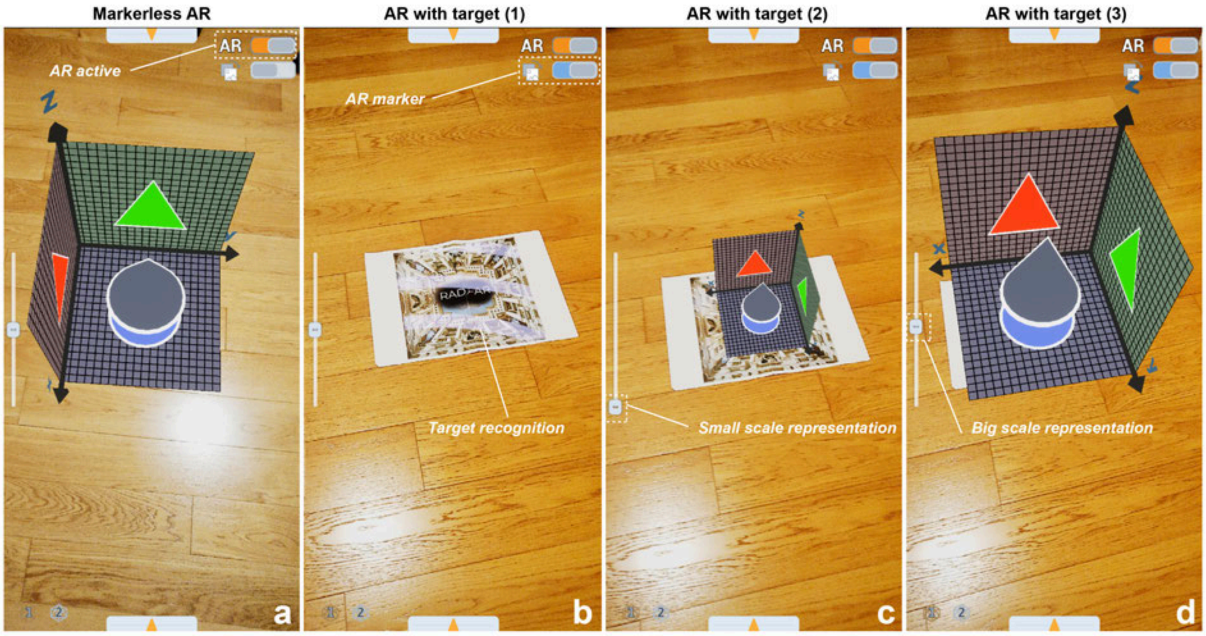

Figure 6. Examples of AR without marker (a), marker recognition (b), visualization of a small-scale (c) and large-scale (d) model.

4.3 Protocol of the general project experimentation

The general protocol consists of testing the use of the APP by constructing graphical primitives following the course contents (Fig. 7). Students may obtain initial feedback on the study they have just tackled, not to mention the level/time of knowledge settling. In geometry courses, fundamental entities (points, lines, and planes) are taught first and 3D solids second, so the experimentation followed these two steps. The testing can be replicated at different levels of training and with different contents, studying the different responses depending on the course level. At the end of each experiment, application usage data is collected, and user responses are processed, verifying the quality of the educational tool and bottlenecks in the learning process. It makes it possible to draw up statistics of the evaluations and plan the subsequent development of the application.

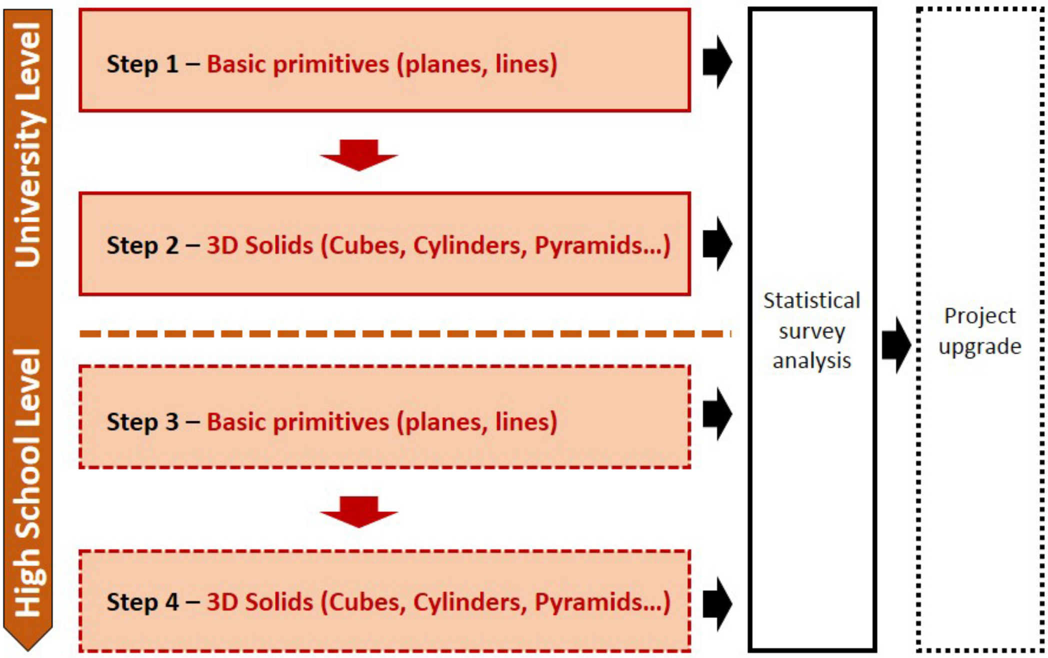

Figure 7. General protocol of the RAD-AR project experimentation.

4.4 Protocol of the classroom experiment

The individual steps are reiterated by varying the type of geometric shapes worked out, defining the specific steps of classroom experimentation (Fig. 8). Since this is an APP validation for the logical and methodological understanding of descriptive geometry, it becomes essential to compare traditional hand drawing techniques with interactive drawing ones through the APP. During the specific protocol, different aspects have been investigated. In the first instance, its use after the hand drawing was tested, verifying its ability to provide the necessary data to achieve the same result. At the end of this phase, the students were asked a few questions about their understanding of the exercise to begin verifying the APP's role from a cognitive point of view in parallel.

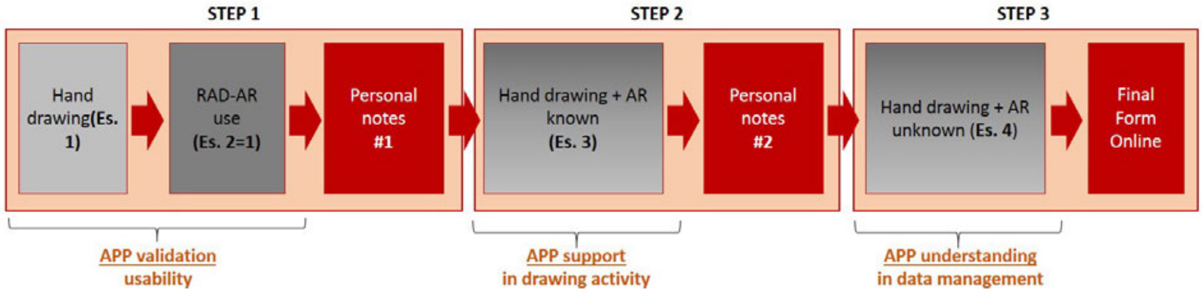

Figure 8. Specific protocol of classroom experimentation.

The second phase involved solving an exercise both by hand and with the APP, providing virtual construction parameters from the outset and leaving the freedom to decide when to use the application. This phase was designed to validate the APP as an operational support tool for traditional drawing, providing a starting foreshadowing or a posteriori verification of a known process. After this second step, some specific questions on the exercise were planned. The last passage involved geometric construction by hand and through the APP without knowing the digital configuration parameters. This step forces the student to directly understand the system for defining virtual geometries, trying to recreate the same manual configuration before or after the exercise. The questions of this phase included the input of the configuration parameters of the APP. At the end of the process, all answers were recorded in a Google form to compare the results obtained.

5 RESULTS

The experimentation was carried out as part of the first-year courses in the Faculty of Engineering and Architecture at Sapienza. The testing phase occupied two days dedicated to fundamental geometric entities and solids, respectively. Regarding the use of devices, more than 80% of the students used smartphones, while the others experimented with tablets, all with the Android system for compatibility limits. The students showed great interest in using the APP as a validation tool for the handwork. Despite their interest in AR, not all understood its potential and adaptability toward personalized learning. It is partly due to a not-so-deep knowledge of AR as a tool to support the understanding of reality.

The form filled out over the two days recorded more than 100 responses. Some questions were differentiated, collecting the results of the exercises and a specific opinion on the APP. In filling in the forms, the students highlighted both the pros and cons of the APP, answering the following six questions:

1. Does the APP appear intuitive, clear, and understandable in general?
2. Regardless of the specific use of the APP to represent a given geometric problem, is access to the various menus and object editing functions user-friendly?
3. Concerning the specific use of the APP, is the sequence of operations leading to the construction and positioning of geometric objects in space clear and comprehensible?
4. Do you consider using the APP alongside traditional teaching helpful in understanding the fundamental geometry entities in space and their relationships?
5. Did the use of the APP enable you to reduce the time needed for hand representation, speeding up the understanding of the process of constructing and relating entities in space? (Students noted down the execution time for each exercise by hand and with the APP)

6 Do you consider AR for visualizing 3D models in real space a valuable approach to understanding geometry in space?

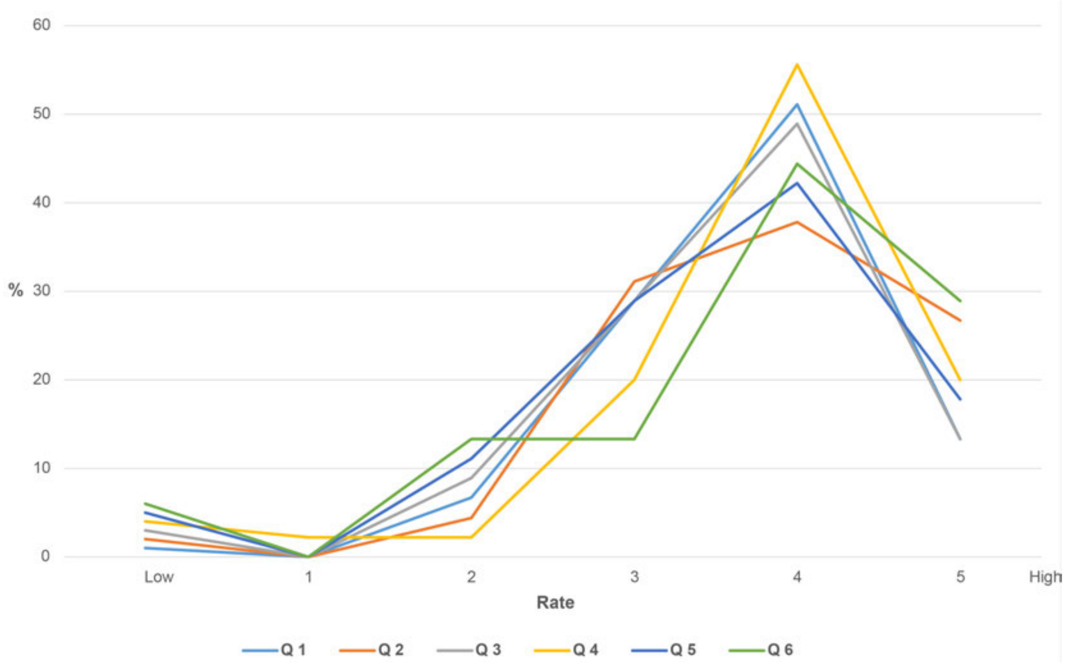

Figure 9. Diagram of the evaluation of the six responses (rate) and distribution percentage (%).

The diagram shows a similar trend of the six answers (Fig. 9). The lowest value is related to access to the different functionalities of the application (Q 2). In contrast, the highest value is related to confidence in the integrated use of this tool in traditional teaching for understanding geometry (Q 4).

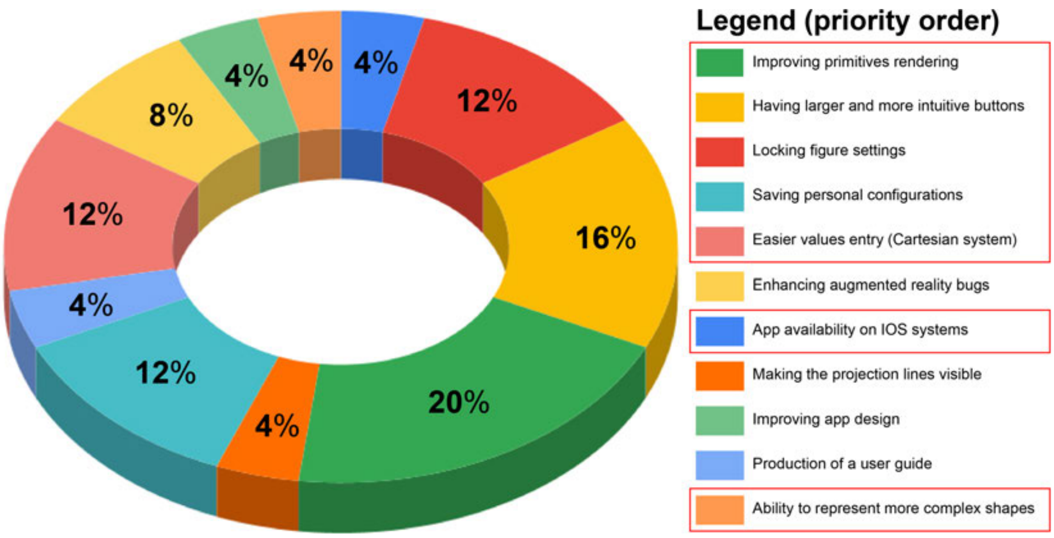

Figure 10. Diagram of critical issues and priorities for APP implementation (squared red in the legend).

The critical points (Fig. 10) highlight certain graphical limitations currently present at the UI level concerning the management of primitives and their positioning and intersection in the fundamental dihedral. In addition, two bottlenecks are highlighted: the absence of an IOS-supported version and the possibility of having a more extensive database of shapes. Both of these issues show a low percentage in the diagram since, in the first case, many students with IOS still need to fill in the form. In addition, the geometric shapes, although few, were sufficient to solve problems calibrated explicitly to those shape databases.

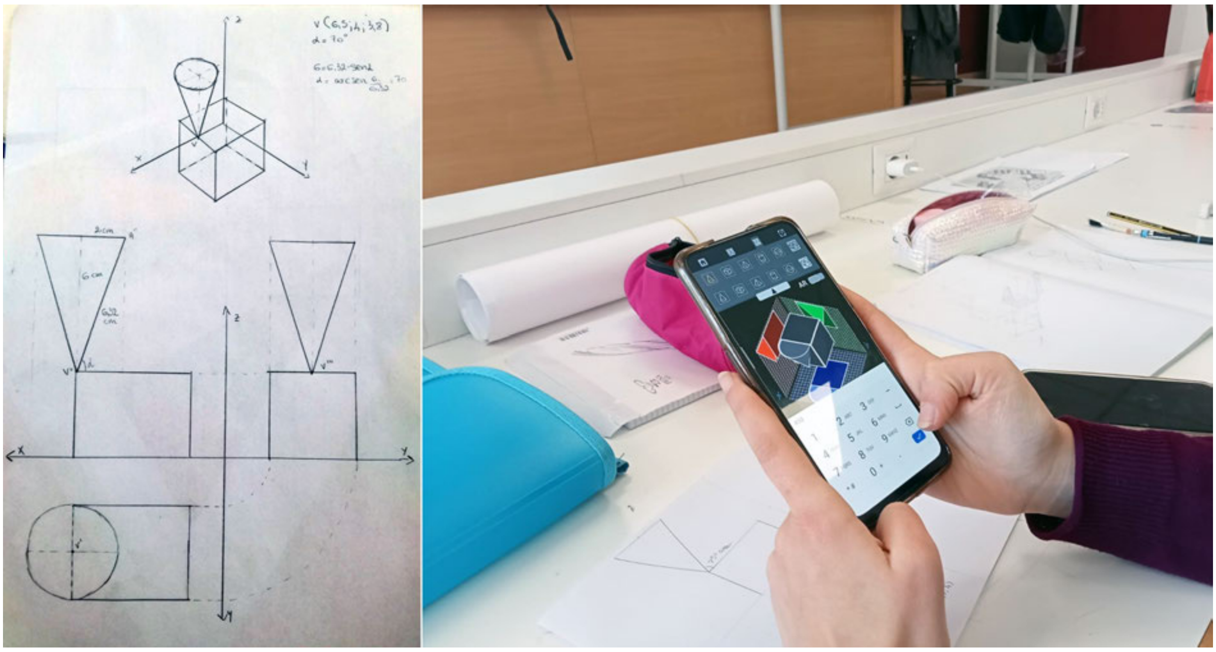

Figure 11. Drawing of one of the classroom tests and testing phase with the APP.

6 CONCLUSIONS AND FUTURE DEVELOPMENTS

This article illustrates the experimentation of the RAD-AR (Representing Active Didactic by Augmented Reality) project, which focuses on the introduction of mobile learning and AR as tools for understanding descriptive geometry (Fig. 11). Through the integrated use of this tool alongside traditional didactics, it was possible to simplify some complex cognitive passages in the field of geometry, such as the projection of shapes in space onto a plane, introducing an engaging and proactive tool in terms of verifying the work done. The APP still has some usability limitations, but the UI was designed to be implementable and scalable. For this reason, experimentation will soon focus mainly on compatibility with other operating systems, the possibility of customizing user settings, implementing the library of geometric shapes, and introducing the representation of a third geometry in the dihedral. In addition, experimentation of the APP with high school students is also planned to start a comparison between users of different age groups. At last, the introduction of AR representation systems in university education can be a scalable proposal for any field in which 3D representation is a vehicle for understanding content or functional processes.

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