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Exploring the Potential of AR: Developing a Parametric Algorithm for Physical-Digital Interaction

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Abstract

The evolution driven by the Internet of Things, cyber-physical systems, and digital transformation redefines our interaction with reality. Among emerging technologies, Augmented Reality (AR) stands out – or could stand out – in sectors such as science and particularly in the field of graphic expression, offering potential beyond the visualization of digital objects in physical environments. This study presents a parametric algorithm for AR to design, position, and accurately measure digital elements in physical environments. Through a typical case study as an example, the methodology is developed in two stages: obtaining the necessary geometry and creating the parametric algorithm to create a mixed reality experience. Using visual programming languages and classical programming, parametric modeling, and BREPS modeling, the geometry of the university logo is recreated. Then, an algorithm is created to create an AR experience to position the geometry, scale it, obtain its measurements, and export these values. This study not only explores the possibilities of AR but also contributes to the advancement of interaction between the digital and physical worlds, opening new perspectives in interdisciplinary design and research.

Keywords
augmented reality, parametric algorithm, mixed reality experience, digitization, XR

Demonstration of the AR app in use, featuring interactive sliders for adjusting the logo's dimensions and position, with the underlying algorithm and exported plaintext data results visible. Photobashing by Pedro G. Vindrola.

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Introduction

The evolution of our world, catalyzed by the proliferation of the Internet of Things (IoT), cyber-physical systems [Kaur et al., 2020], and the ongoing digital transformation process, is changing how we live, work, and relate to reality [tom Dieck & Jung, 2018]. This transformation is becoming increasingly evident in our day-to-day lives, especially with the launch of new XR displays, which are already starting to be seen in public transportation, restaurants, gyms, etc.
Today, the convergence of technology and communication has given rise to what is commonly known as the information and knowledge society [Castells, 1996]. Over the past five decades, many computer tools have emerged that serve as valuable resources for knowledge dissemination and sharing but also stretch the human mind and body in the liminal space between reality, the metaverse, and society [Mann, 2023]. In addition to this emergence, IT tools now have an unprecedented ease of accessibility and massiveness. These include software development kits (SDK), plugins, add-ons, simpler programming languages, and, within the latter, incredibly visual programming languages that work within sector-specific software.
On the other hand, we are also seeing a boom in the use and popularity of technologies capable of creating mixed reality experiences or, more accurately, experiences that are part of the virtuality continuum (VC) – between the reality and the entire virtuality – [Milgram & Kishino, 1994]; or also that are part of the updated VC, the Reality-Virtuality continuum [Skarbez et al., 2021]. These experiences are also known as Mixed Realities (MR), one of the many definitions of this ambiguous concept [Speicher et al., 2019]. The technologies that create these experiences are popularly known as Extended Realities (XR). Augmented Reality (AR) stands out within these technologies, particularly in the science, research, and private sectors, due to its undeniable potential. It is no coincidence that large companies have bet heavily on developing hardware and software to create experiences that can be categorized as AR [Apple ®, 2024; Meta ®, 2021; Microsoft ®, 2016]. In the design and graphic representation sector, we have quickly embraced the potential of AR to look at digital objects superimposed on reality for both existing things and new projects [Vindrola, 2023].
In this context, AR emerges – or may emerge – as a powerful tool in various fields, offering unexplored potential beyond the mere visualization of digital objects in real environments [Abergel et al., 2019; Atanasova et al., 2022; Jahn et al., 2020; Lharchi et al., 2019]. In this sense, the present work aims to develop a parametric algorithm for an AR experience [Antuono et al., 2024] to support design by measuring and positioning digital elements in physical environments. This algorithm makes it possible to accurately assess the position and size of digital objects, offering an invaluable tool for creation and research in various fields. Through this study, we seek not only to explore the possibilities of AR but also to contribute to advancing the interaction between the digital world and the physical world.

Case Study and Modeling

To test the operational methodology, the case study was chosen in a building designed by Luigi Cosenza, today the engineering headquarters of the University of Naples Federico in Piazzale Tecchio, Fuorigrotta (Naples, Italy) (fig. 1). In the recently remodeled former faculty council chamber on the second floor of the building. Then, the Athenaeum of the University of Naples Federico II logo was used to test the AR application.
The methodology is divided into two stages; the first is to obtain the necessary geometry to use it to augment the reality; in this case, both the modeling of the Athenaeum logo and the construction modeling will be used for the AR experience. The second stage is the creation of the parametric AR algorithm to fulfill the objective previously stated in the introduction of this article. It is appropriate to clarify that the first stage functions as an example of the second stage of the methodology. In other words, the case study is the necessary input for correctly developing the parametric AR algorithm in the second stage. Therefore, this first

Fig. 1. Case study, University of Naples Federico in Piazzale Tecchio. A) Outside View; b) first-floor plan of the building; c) Inside of the building, remodeling of the former faculty council room on the second floor of the building, today Bovio aula. Image by Pedro G. Vindrola.

stage could be changed for another without affecting the AR application's performance (fig. 2).

To start with the methodology, a simple modeling of the room's walls was done in which the logo was to be positioned. This modeling was done in Rhinoceros 3D since the AR part was done using the plugin of this software, Grasshopper (GH). Then, a high-quality image of

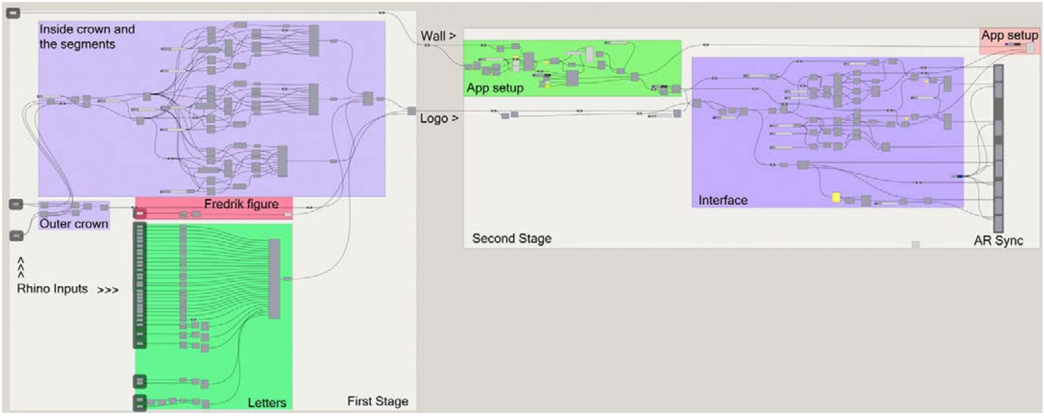

Fig. 2. Methodology. Image by Pedro G. Vindrola

the logo was vectorized (in .png format), obtaining the logo in .svg format (Scalable Vector Graphic) (fig. 3). The .svg was imported into Rhinoceros software and exploited to obtain independent curves. This allows the curves to be set separately in the Rhino plugin, Grasshopper (GH). At this stage, the outer crown is recreated uniformly in a parametric way, and the inner crown segments also in a parametric algorithm but with some manual steps. At the same time, the letters and the 2D representation of Frederick II are fixed directly and converted to surface (fig. 3).

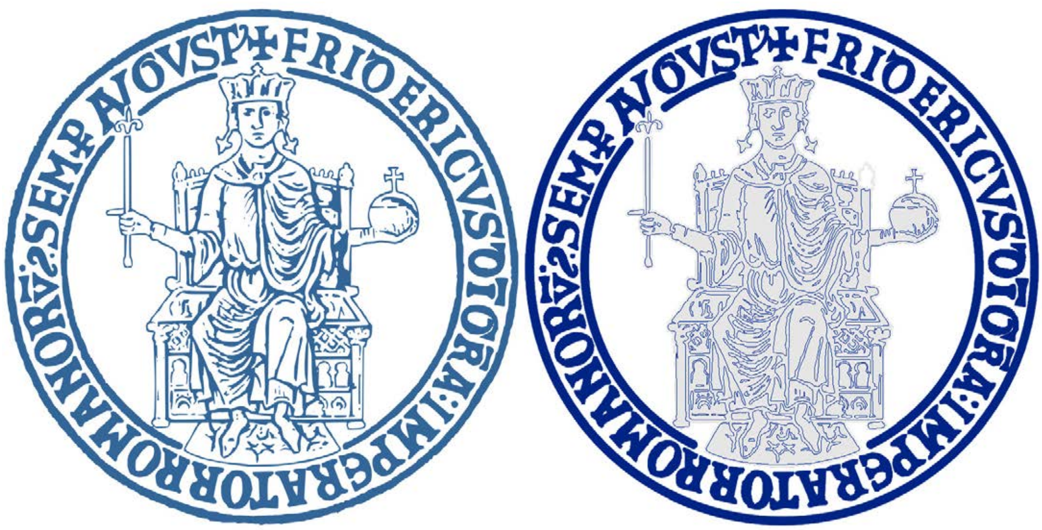

Fig. 3. On the left is the high-quality logo of the University Federico II. On the right is the parametric reconstruction. Image by Pedro G. Vindrola

In the GH canvas, the two curves, or rather the two polygonal approximations of the circles, that describe the crown are first set in different components. From these, with the 'Boundix Box' component configured as 'Union Box,' the centroid of this was calculated, and then the distance of 2 of the vertices of 'Boundix Box,' thus obtaining the diameter of the polygonal approximations of the circles. Then, we created the two parametric circles. The first is from the centroid and half the distance of the vertices of the outer curve; the second is with the subtraction of the distance of the inner curve and the centroid of the outer curve. Then, a 'Loft' was made with the two circles to obtain the uniform outer crown.
The same concept of creating two circles was used to recreate the inner crown segments. These were divided based on an arbitrary number, in this case, 120; thus, 120 points were obtained. With the division, the closest points describing the three segments of the inner

crown were taken. Then, the start, mid, and endpoints (for the outer and inner curves) were separated for each of these segments. Then, for each curve, the points with an index +1 and -1 from the start and endpoint of each segment, respectively, were separated too (fig. 4). In other words, if the segment started at the point with index 30 and ended at point 80, the curve was described by an arc from point 30 to 80 (with the mid-point at the index 55) and points 29 and 81 were also taken separately.

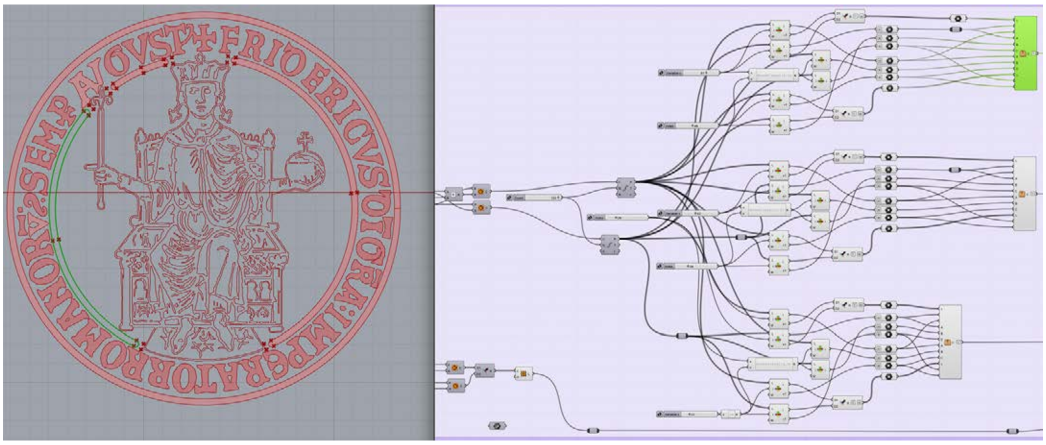

Fig. 4. On the left, the interface of Rhinoceros3D shows the points used to recreate each of the three segments of the inner crown. The segment selected in Grasshopper is highlighted in green. On the right is the algorithm for creating the crown segment, with the cluster chosen for making the same segment highlighted in green. Image by Pedro G. Vindrola.

These +1 and -1 points are used to create the semicircle that joins the inner segment with the outer one. For this, we created and used the 'Arc 3Pt' component to start and finish the ends and beginnings of the curves. As the center, the midpoint of the line segment is defined by the two separate points. Continuing with the example, for the two segments, the curve that starts at point 30 and ends at point 80, the pair of points 30 is used, one as the beginning and the other one as the end of the arc, while the midpoint of the 'Arc 3Pt' is created between the pair of points 29 is used as the intermediate point. Finally, the pair of arcs and curves are joined to convert them into a surface. To avoid repeating this step for each crown segment, a cluster was created, with the points and curves as inputs and, as an output, the curve of the segment (fig. 5).
Then, continuing with the modeling part, we had to make the geometry of the letters and the figure of Frederick II. For the letters there are two types of letters: the simple letters, the letters that do not have closed curves in the interior that have to be extracted from the surface, such as the letter F; and the second type, the letters to which part of the interior surface has to be removed, as O. The first type is set from the curve component, one or more curves at a time, and then connected to the surface component. The second type, the 'Surface Split' , must be added afterward to extract the curve from the inside of the surface. Subsequently, in the figure of Frederick II, a surface is created from the outer curve of the figure, previously set, and the inner curves of the figure were also set.

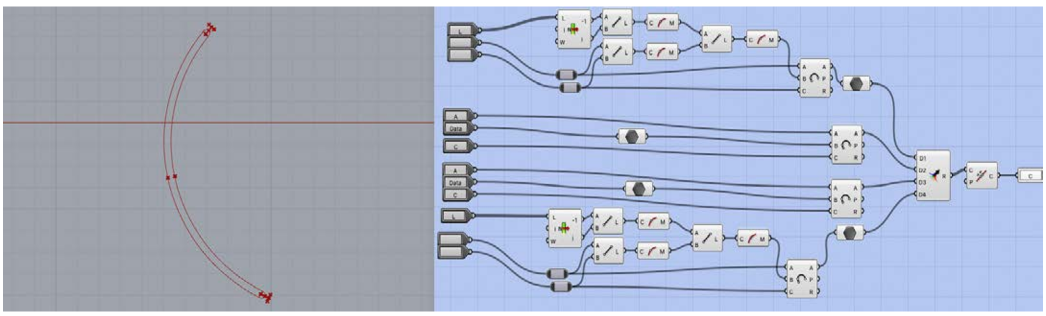

Fig. 5. On the left, the curves and points that, after being joined, create the crown segment. On the right is the cluster for creating the crown segment from the points. Image by Pedro G. Vindrola.

Finally, to finish the modeling part, the outer crown and the segments of the inner crown, on the one hand, and the letters and the inner lines of the figure of Frederick II, on the other hand, were grouped. These two groups and the surface of the figure of Frederick II were then merged to obtain a single component with a tree structure that contains them.

Augmented Reality Experience

For the second stage of the methodology, where the parametric algorithm is created to position a digital object in a real environment and evaluate its position and size, GH, Fologram—Grasshopper's plugging—and Python were used. Fologram allows synchronizing different GH elements to be viewed in AR and/or interact with them. The synchronization of the digital elements to reality is given from 'Connect'—Fologram's command—and, therefore, also the elements of GH, with a display. In turn, Fologram has a system of 'XRMarkers' that allows us to superimpose the digital model's Cartesian system to the real world's Cartesian system. In the case of this methodology, an 'XRMarker' was used, which in turn was used as the origin; the reason for this will be explained later.
To start the algorithm in this stage, we first set only the wall surface where the logo will be located, which was previously modeled in Rhinoceros. From this surface, a plane was created with its origin at the center of the surface area. From this plane, we made a grid of points every 20 cm, which, first, are used to create a sphere for each point. Second, the points are also used as input in Python code. This Python code has as input a 'Boolean Toggle' to reset the object's position, a Python class to handle the persistent data in this algorithm, and two material inputs, one transparent and one not, to make the spheres transparent when selected.
Continuing, once a geometry is selected through the 'Sync Geometry' and the 'On tap' Fologram components, the index of the point in the grid is obtained. The last index, the grid of points, and the instance enter another Python code responsible for filtering the selected

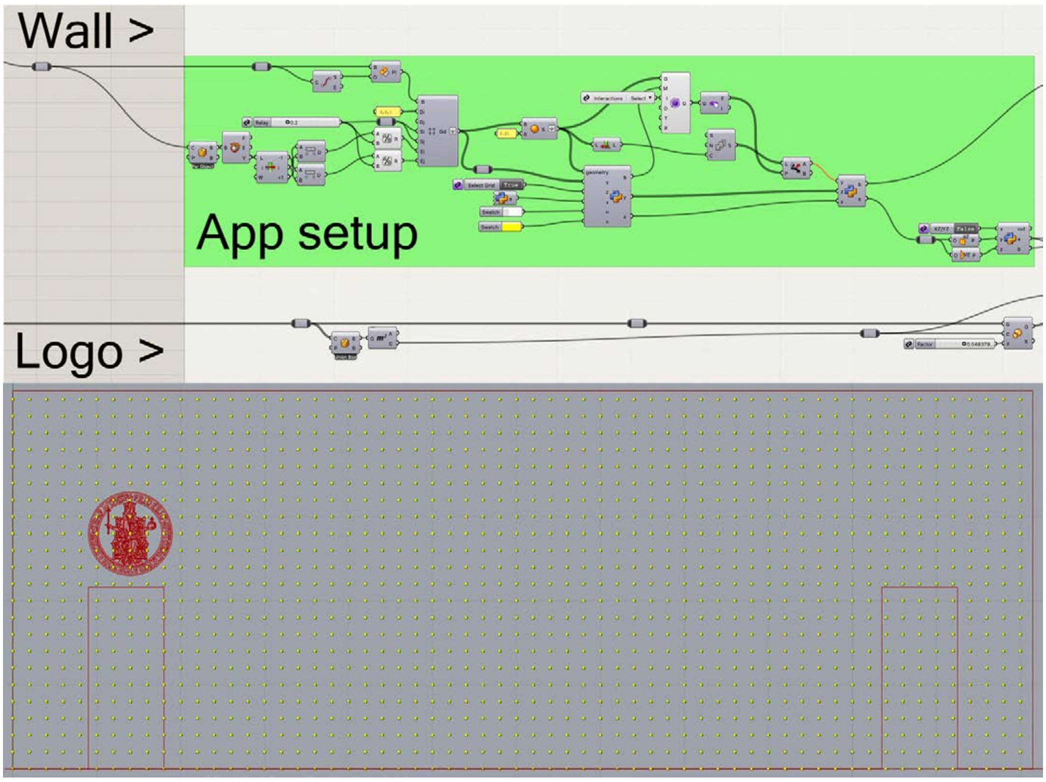

Fig. 6. On the top, the algorithm for selecting the grid and how it is synchronized can be seen. On the bottom, the result on Rhinoceros, the alignment of the logo plus the spheres in the wall, can be seen. Image by Pedro G. Vindrola.

point and creating a point with it in two formats, text, and GH point format. With this information, the logo is oriented using as a new plane the wall that has as its origin the selected point. Then, a synchronized slider was created in AR so that the user could scale in the position chosen previously. (fig. 6)
To finish this methodology, the part of the user interface and the part in charge of exporting the measurements and position of the object are created. First, a 'Boundix Box' of the scaled logo is made, and the points are extracted from it. These points are moved on the z-axis and toward the wall plane. The distance is measured with these walls, and the texts are created from them. This information is synchronized as a dimension as a user interface.

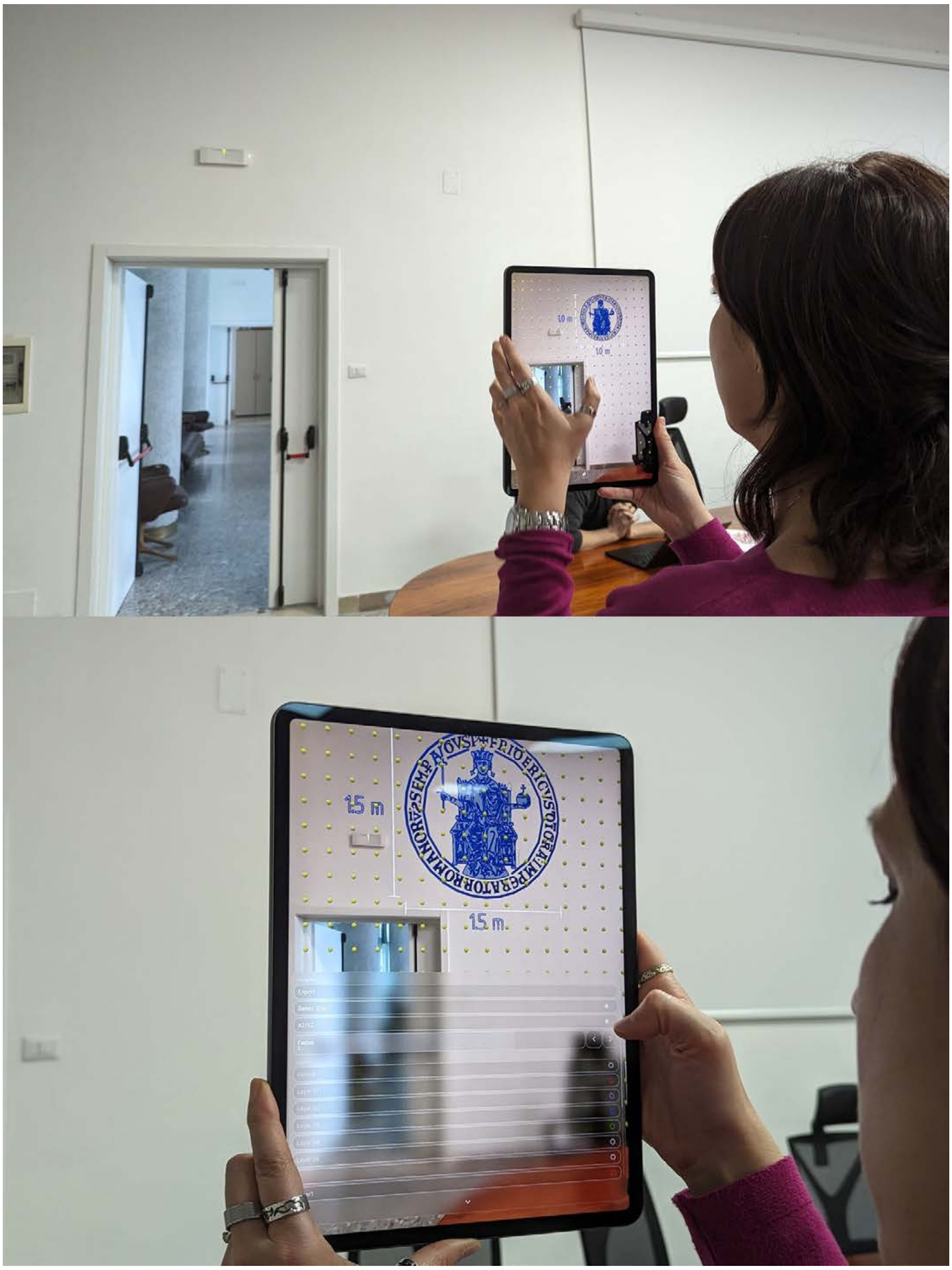

Fig. 7. On the left is the interactive menu of the AR experience. On the right top angle are two examples of the files that are exporter, while on the right bottom angle is the Python algorithm, where 'x' is the position of the logo, 'y' is the measure on the axis of the direction of the plane of the wall, and 'z' the measure on the Z axis. Image by Pedro G. Vindrola.

All the geometry groups are ungrouped and synchronized, following the logo's colors with the 'Sync Geometry' component. Finally, to export the data, a Python code is used, which inputs a button named Export, synchronized in the AR experience, the point's text value, and the dimension's two values. This Python code, through the fulfillment of logical conditions, exports – in this case – to a .txt format, which can be seen in the image (fig. 7). The position obtained is relative to the origin of the digital Cartesian system, therefore to the Marker placed in the reality.
After the methodology was completed, the users used the application to give their opinions about the position and size of the logo in the room (fig. 8).

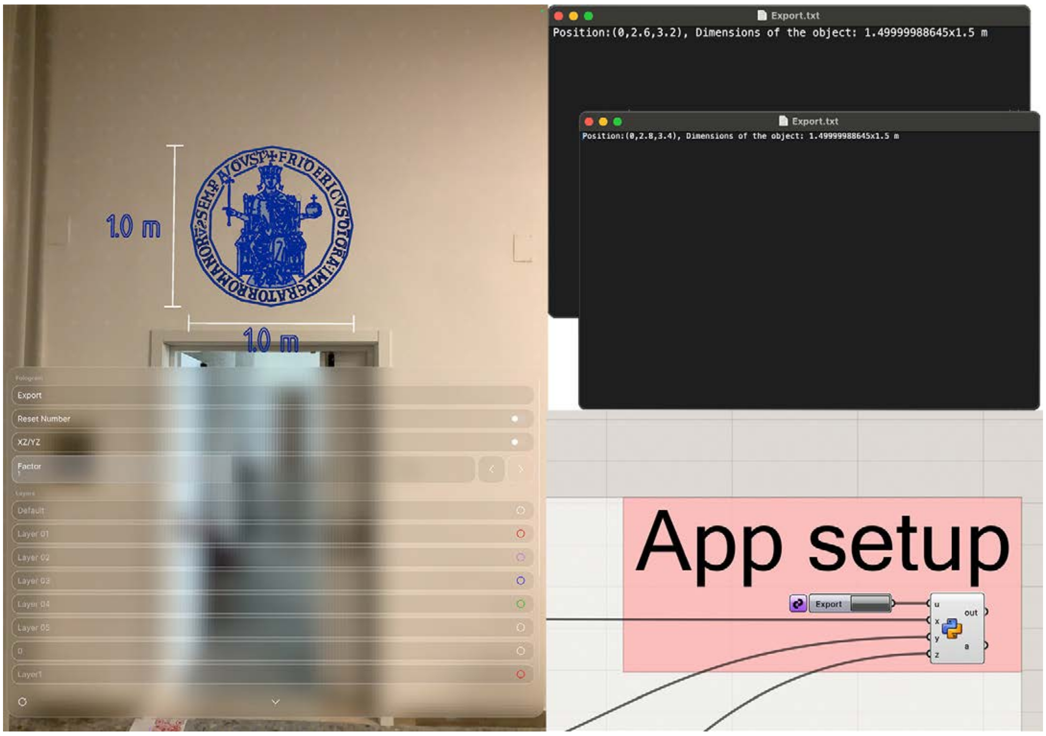

Fig. 8. Using the application, the user changes the size of the logo on the wall by clicking the slider. Image by Pedro G. Vindrola.

Conclusion

In conclusion, this study has explored the potential of Augmented Reality (AR) as a powerful tool in various fields, highlighting its ability to redefine the interaction between the digital and physical worlds. The article presents a parametric algorithm for creating an AR experience that accurately designs, positions, and measures digital elements in physical environments. This algorithm not only facilitates the creation of mixed reality experiences but also contributes to the advancement of interaction between the digital and physical worlds.
This study allows us to evaluate and compare the position and size of the logo preferred by different people. It is essential to highlight that this study focuses not only on the technology itself but also on its practical application and implications in the real world of the construction sector. In this case, the values obtained from the user interaction were exported to a .txt format. Still, they could be exported in other formats or even to other software fields [Elefante & Vindrola, 2024].
In summary, the parametric algorithm for AR presented in this study is simple to implement, using different tools already used in the graphics industry. At the same time, it explores how AR can transform the way we interact with the physical environment, opens new perspectives in design and interdisciplinary research, and, perhaps most importantly, shows the impact that AR can have on our society.

Fig. 9. Discussion of the measures and position of the logo with colleagues. Image by Pedro G. Vindrola.

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