# A Proof of Concept on Enhancing Virtual Museum Experience Through Real-time Audio Communication

Calíope Corrêa de Araújo
Universidade Federal de Pernambuco
Recife, Brasil
caliope.araujo@ufpe.br

João Marcelo Xavier Natário Teixeira
Universidade Federal de Pernambuco
Recife, Brasil
jmxnt@cin.ufpe.br

***Abstract*—By introducing the possibility of communication within a virtual environment, it is possible to improve visitor interaction and increase immersion through the feeling of presence, a fundamental concept within Virtual Reality. This work therefore proposes an innovative solution to the problem of lack of interaction between visitors during a virtual tour using open source software resources. Making use of the A-Frame framework, together with Networked A-Frame, a proof of concept was implemented with the aim of showing that it is possible to improve the experience of a virtual visit to the museum, enabling visitors to communicate in a very similar way to what would happen in a real visit, in a physical space. A brief case study was carried out based on the creation of an alternative virtual tour, modifying the existing virtual tour of the Cais do Sertão Museum, in Pernambuco, with the proposed solution. This paper will explore the paths used to build the proof of concept, as well as the results obtained and possibilities for future work, in addition to presenting possible scenarios for applying the proposed solution seeking to improve immersive experiences in virtual tours of museums.**

***Keywords*—Virtual Museum, Virtual Tour, Multi-user VR**

## I. Introduction

With the inevitable technological evolution, museums and cultural spaces have undergone modifications in their structure, often adapting to new realities and embracing the possibility of virtual visitation to their collections as a means of preservation and dissemination of heritage. One of the major challenges facing these spaces today is to offer attractive ways of interaction and communication to the public. According to Sandy [1], a museum is much more than just a technical reserve and a few exhibition rooms; it is also a place where cultural and civic values are enhanced. Therefore, it is important to plan strategically to attract the public to the space, whether physical or virtual, and to provide this same audience with a strong and profound connection experience with the exhibited object.

The simultaneous existence of traditional/concrete museums and virtual museums is a hallmark of the contemporary artistic and cultural scene. Despite their convergence in terms of their museological functions of preserving and providing informational content in the field of arts, the architectural and physical distance is evident [2]. Therefore, it is necessary to look at the gap between the real and the virtual worlds in terms of visitation and understand where there are gaps that differentiate these experiences in order to develop new approaches, bringing virtual visitors closer to the experience previously sought by museums and cultural spaces.

When the museum visitation experience moves to the virtual realm, the scope of action widens, giving rise to multiple interactive paths. In an attempt to represent the real world, a new reality is created, parallel and coexisting with the first one, which should be seen as a set of new perspectives on the traditional museum [3]. Analyzing new possibilities, some challenges still need to be overcome to make the virtual visitation experience even more immersive. One of these points relates to interactive, spatial, and environmental communication in the experience. If a person goes to the museum in the physical space, they not only experience the visualization and contemplation of the exhibited works and collection but also interact with other visitors.

We already know that humans are social beings, and what they learn is mediated through conversations, gestures, emotions, observing others, historically constructed culture, signs and symbols, social beliefs, values, and norms. Thus, identity and behavior result from the sociocultural context in which people are immersed. Visits to museums are embedded within a context with a strong social and cultural component. It is observed that most people visit museums in family or school groups; even those who choose to visit the museum alone

are always in visual or verbal contact with other visitors or mediators. In museums, the main social interactions are verbal – conversations – that occur within the family group, between parents and children, between visitors and mediators, between teachers and their students, and within the group of students, among other possibilities [4].

Imagine you are in a museum. Even if you decide to visit alone, during your walk, you can see people around, contemplate their reactions to each work, hear comments from other conversations, learn from others, get to know the profiles of other visitors, hear the ambient sounds, and so on. If you decide to visit with others, you can still discuss the artworks, engage in discussions on various topics, exchange experiences, and even hear the reactions of other visitors, influence, and be influenced by others' behavior. This type of collective, perhaps even collaborative experience, is straightforward when we think about the physical space of the museum, but when seeking solutions that bridge the gap between the real and the virtual world, it is necessary to think about how these important communication experiences would take place in a virtual environment.

A virtual visitation can be done, for example, and mostly, through online navigation, using a virtual tour created with panoramic images, in 360 degrees, and applications that enable navigation. On the Google Arts and Culture platform [1], you can visit museums from all over the world, view virtual exhibitions, and interact with numerous artworks in their collection. Furthermore, you can search for the most famous museums in the world or explore museums near your region, using integration with Google Maps. There are thousands of virtual tours on the internet accessible to visitors, and many features have already been implemented to enhance the virtual visitation experience and enhance the immersion process, such as textual information about the collection, links associated with artworks that lead to other sites with detailed information, audio descriptions, narration, and even background music. But one existing gap in these virtual tours is the lack of real-time online interaction and communication with other visitors, distancing the virtual visit from the real experience.

By introducing the possibility of communication within a virtual environment, enhancing visitor interaction, we increase immersion and reflect on the sense of presence, a crucial concept in the field of virtual reality. Immersion can be an objective and quantifiable description provided by a specific system, which can have various degrees. Presence, on the other hand, is a state of consciousness, the psychological sensation of being in the virtual environment, and can be defined as a growing function of immersion in all its aspects [5]. The sense of presence is a complex study but relates to an individual's feeling of being present and integrated into a virtual environment. By incorporating communication into the virtual tour of a museum, which can be viewed from a computer or even using virtual reality devices, this work provides visitors, based on the concept of the sense of presence, with a closer approximation of their experience to real physical visitation in a physical space.

This work proposes a solution to the problem of lack of interaction among visitors during a virtual tour, using free and open-source computing resources to create a system that allows museum visitors to communicate in a way very similar to what would happen during a real visit, in a physical space. Using the A-Frame framework, in conjunction with Networked A-Frame, a proof of concept was implemented with the aim of showing that it is possible to enhance the experience of virtual visitation through communication. In this paper, the step-by-step process used to build the proof of concept, as well as the results obtained and possibilities for future work, will be explored.

## II. Virtual Museums

The Municipal Secretary of Education of São Paulo conducted a survey in 2020, listing 30 options for virtual tours where it's possible to visit various museums in Brazil and around the world. Among the most famous museums, we can mention the Louvre Museum and the Palace of Versailles in Paris, France, the Metropolitan Museum of Art and the American Museum of Natural History in the United States, the National Museum of Contemporary and Modern Art in South Korea, as well as many museums in Brazil, such as the Pinacoteca of the State of São Paulo and the Museum of Tomorrow in Rio de Janeiro. What these mentioned virtual tour options have in common is that they offer an online navigation experience through museum areas or exhibitions presented in their spaces, using 360-degree images and navigation, where the visitor can be transported through registered images that depict the environments and artworks. Visitors can also learn more about the collection from the information available on the tour and even listen to a guide or narrator explaining about the artworks.

In Brazil, there are currently 3,887 museums cataloged by the Brazilian Institute of Museums (Ibram) [6], and the most up-to-date source for learning about Brazilian museums is through Museusbr [7], a national system for museum identification and a platform for collaborative mapping, management, and sharing of information about Brazilian museums. Its purpose is to provide electronic information about Brazilian museums,

[1]Google Arts and Culture is a platform developed in partnership with museums that offers free virtual visits to some of the largest art galleries in Brazil and the world, using the same technology as Street View.

in all their diversity, to produce knowledge about the museum sector in Brazil.

Based on a survey conducted through this platform (the same as mentioned earlier), 134 museums were identified in the state of Pernambuco, where this research was conducted. All registered museums in the state were visited virtually from their official webpages provided by the platform, and within this search, it was noted that museums in the state of Pernambuco do not yet offer a virtual tour through their own institutions or on their official websites.

Some virtual tour options in museums in the state were found through third-party creations or cultural heritage preservation projects. For example, the company M360 Virtual Tour digitized Forte do Brum in Recife, Pernambuco, and made it available on its webpage. The company GoPasseios also offers virtual tours of some museums in Pernambuco, such as the Museum of Modern Art Aloísio Magalhães and Paço do Frevo in Recife, as well as the Museum of the Sertão in the city of Petrolina. Some of these experiences can also be found on the Google Street View platform. Furthermore, there are private institutions like the Catholic University of Pernambuco, which has a virtual tour of its Museum of Archaeology and Natural Sciences of Unicap, and the Pernambuco Sanitation Company, which offers a tour of the Compesa Universe Museum.

In 2022, the Secretary of Science, Technology, and Innovation of Pernambuco (Secti/PE), in partnership with the State Secretary of Culture (Secult/PE) and the State Secretary of Tourism and Leisure of Pernambuco (Setur/PE), assembled a team to create the first Virtual Museum of Pernambuco. The digitization was carried out using technology similar to the Action Camera 360, which allows for an interactive virtual visit, in a 360-degree style. The experience is hosted on the Museus Digitais portal [8], and the Cais do Sertão Cultural Center was the first museum in Pernambuco to be digitized under the Patrimônio Pernambuco Digital project. So far, Cais do Sertão Digital includes audio description, navigation control, and high-definition images that can be rotated and turned by the visitor. Secti states that the next museums to be digitized will be the Museum of the State of Pernambuco, Cinema São Luiz, Museum of the Train, and the Science Center.

From the information analyzed, it was possible to see that no digital museum in the state of Pernambuco, where this research is being conducted, and none of the museums in Brazil or around the world visited during this analysis, offer visitors the option to interact with each other through verbal communication within the virtual tour in real-time using chat, audio, or video resources. Therefore, the solution proposed in this work was designed to be initially applied to virtual museum visits in the state of Pernambuco, primarily as a free, easily implementable solution, achievable with accessible devices, and one that offers an improvement in interaction and immersion within the virtual environment, directly contributing to the attraction of these spaces, the preservation and dissemination of artworks and collections, and the appreciation of the state's cultural heritage.

## III. The Proposed Solution

A-Frame is an open-source framework for developing web-based virtual reality (VR) and augmented reality (AR) content [9]. It was developed by Mozilla and is one of the most popular tools for creating accessible VR/AR experiences through web browsers that support WebXR technologies, such as WebVR and WebAR.

A-Frame is built on top of HTML, making it easier for web developers and designers to create VR and AR scenes without the need for advanced knowledge of 3D or VR programming. It uses an "entity-component" approach, where entities are the 3D elements of the scene (such as objects, cameras, and lights), and components are attributes that define the behavior and characteristics of these entities.

Networked A-Frame is an extension of A-Frame that allows the creation of multi-user VR experiences, where multiple people can interact in a shared VR environment over the internet. It adds networking and synchronization features to A-Frame, making it possible to create shared VR experiences. This means that users can enter the same VR scene simultaneously and interact with each other in real-time, regardless of their physical locations, as long as they have internet access and VR-compatible devices.

The main advantage of using Networked A-Frame is that most of its features are provided transparently. For example, Figure 1 illustrates a scene defined in the original version of A-Frame and the same scene, now defined using Networked A-Frame, with support for multiple users. Note that it was only necessary to include a few attributes along with the "scene" element (in addition to the library at the beginning of the file). The illustrated example allows multiple users to access the same virtual environment and see a representation of each other's avatars in real-time, with position and orientation information, as shown in Figure 2.

The proof of concept proposed was based on two examples provided by the Networked A-Frame library: 360.html and basic-audio.html. In the first example, a 360-degree image in equirectangular format is displayed around the user, while in the second example, a virtual environment with audio communication is demonstrated (as illustrated in Figure 2). In addition to combining the two examples, other modifications were necessary, such as adding code for "hotspots" (links between different rooms in the virtual tour) and background sound for narration in some rooms.

```
<!-- Original A-Frame code -->
<a-scene>

<!-- Modified Networked A-Frame code -->
<a-scene networked-scene="room:basic-audio; debug:true; adapter:easyrtc; audio:true;">

<!-- Avatar -->
<template id="avatar-template">
    <a-entity class="avatar" networked-audio-source>
      <a-sphere class="head" scale="0.45 0.5 0.4"></a-sphere>
      <a-entity class="face" position="0 0.05 0">
        <a-sphere class="eye" color="#efefef" position="0.16 0.1 -0.35" scale="0.12 0.12 0.12">
          <a-sphere class="pupil" color="#000" position="0 0 -1" scale="0.2 0.2 0.2"></a-sphere>
        </a-sphere>
        <a-sphere class="eye" color="#efefef" position="-0.16 0.1 -0.35" scale="0.12 0.12 0.12">
          <a-sphere class="pupil" color="#000" position="0 0 -1" scale="0.2 0.2 0.2"></a-sphere>
        </a-sphere>
      </a-entity>
    </a-entity>
</template>

<!-- User avatar shared by Networked A-Frame -->
<a-entity id="rig">
    <a-entity id="player"
              networked="template:#avatar-template;attachTemplateToLocal:false;"
              camera
              position="0 1.6 0"
              spawn-in-circle="radius:3"
              wasd-controls
              look-controls>
      <a-sphere class="head" visible="false" random-color></a-sphere>
    </a-entity>
</a-entity>
```

Figure 1. Comparison between the original A-Frame code and the version with network support provided by Networked A-Frame. The yellow highlighted region illustrates the attributes added to make the avatar shared. Source: https://naf-examples.glitch.me/basic-audio.html

## IV. Case Study: Cais do Sertão Museum

The Cais do Sertão Museum is an interactive museum about the Sertão and Luiz Gonzaga located in the city of Recife, capital of Pernambuco, Brazil. One of the most important museums in the State as it is one of the most visited physically and was the first to receive a virtual tour. Due to its importance, and because it is considered the first museum of the Pernambuco Digital Project [8], it was the museum chosen to experiment with the solution, as described below.

With the basic structure of the proof of concept defined, we sought to reimplement an existing virtual museum with the aim of comparing the current experience with the one including real-time audio communication in the future. From the limited variety of virtual museums found in a previous search focusing on the state of Pernambuco, we chose to create an alternative version of the Cais do Sertão Digital Museum [8].

By analyzing the digital version of the museum, it was possible to determine that it uses KrPano as a tool for enabling the virtual tour and panoramas (images captured with 360-degree cameras) of various museum environments. KrPano, widely used for this purpose, implements several optimizations to make web browsing experiences smoother. One of these optimizations is dividing the panorama into small patches, using a cubemap representation (six images, one for each face of the cube surrounding the user) instead of a single equirectangular image. For each of the six faces, the images are further divided into 4 parts, totaling 24 different images (illustrated in Figure 3) that need to be ”stitched” and subsequently transformed into equirectangular format, as it is the only format supported by the original A-Frame version. The tool available at https://danilw.github.io/GLSL-howto/cubemap_to_panorama_js/cubemap_to_panorama.html was used to perform the transformation from cubemap (6 images of the cube faces) to equirectangular representation, as shown in Figure 4. The following associations were used:

- 0: right

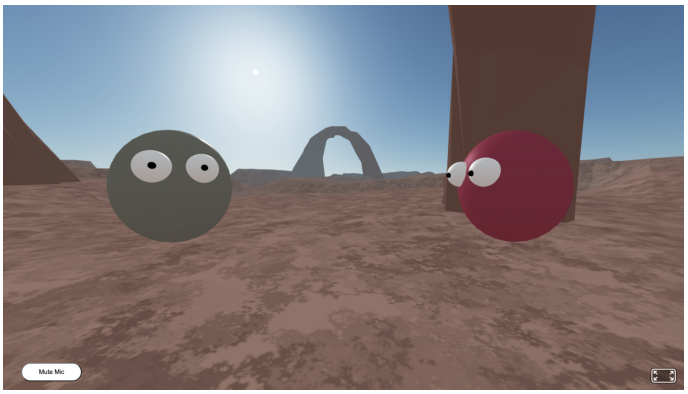


Figure 2. Minimalist example of Networked A-Frame that allows multiple users to share the same virtual environment and enables audio communication among them.

- 1: front
- 2: left
- 3: back
- 4: up
- 5: down.

The p360tour.xml file, located within the online KrPano project folder, contains all the information about the virtual tour at the Cais do Sertão Museum. It was possible to identify the number of specific scenes (panoramas) used (a total of 109). Additionally, 9 audio tracks are used in some of the defined scenes. Finally, there is an average of 4.11 hotspots per scene (a total of 448).

Due to the amount of information in the xml file, it was necessary to develop a Python script capable of parsing the file, collecting the necessary information to build the HTML files for each scene. The following information were extracted from each scene located in the xml:

- **name** (indicates the name/number of the specific panorama).
- **backgroundsound** (indicates if there is and what is the background sound to be played in that specific scene).
- **thumburl** (this URL was used to obtain the link for downloading the panorama ”patches” for subsequent reconstruction).

Additionally, for each hotspot found within a scene, the following information were extracted:

- **ath** (horizontal angle, used as one of the spherical coordinates to locate the hotspot in space).
- **atv** (vertical angle, used as one of the spherical coordinates to locate the hotspot in space).
- **parameter of the mainloadscene function call** (indicates the destination panorama when the hotspot is triggered).

Since the location of hotspots in A-Frame is based on 3D coordinates and does not use spherical coordinates, a conversion between the values was necessary. The following code snippet was used for an approximate conversion of the hotspot locations in each scene:

```
ath = math.radians(float(te.get("ath")))
atv = math.radians(float(te.get("atv")))
r = 20
x = r * math.cos(ath)
z = r * math.sin(ath)
y = r * math.sin(atv)
```

After converting the ath and atv values from degrees to radians, the coordinates were calculated. Note that the y-axis represents the vertical axis of the panorama, while x and z represent the plane parallel to the ground.

The assembly of specific pages was also implemented within the same script that parsed the xml project file. A base HTML page was defined, with key positions that were replaced by the content found in each scene:

- **__ROOMNAME__**: used to define both the name of the HTML file to be generated and the name of the room to be used by Networked A-Frame.
- **__AUDIOURL__**: used to define when there was audio to be played in a particular scene.
- **__PANORAMAURL__**: associated the panorama file with the scene.
- **__HOTSPOTS__**: represented the location within the HTML file where information about the generated hotspots would be inserted, after converting spherical coordinates to Cartesian coordinates.

Finally, the generated files were hosted on the Glitch platform, which facilitates the development of client/server solutions, allowing for on-the-fly editing of files and viewing the results in the browser. Additionally, the tool can be used for free, with some minor limitations.

The implementation result can be accessed at https://marked-level-purchase.glitch.me/. Navigation and communication tests were conducted on different devices, including laptops and mobile phones (both Android and iOS). Successful voice communication tests were conducted in each panorama, as well as navigation between different panoramas.

## V. Possible Scenarios

Based on the proposal of this project, ideas for future scenarios can be considered to solve problems or fill gaps related to the visitation and interaction of museums and collective cultural spaces.

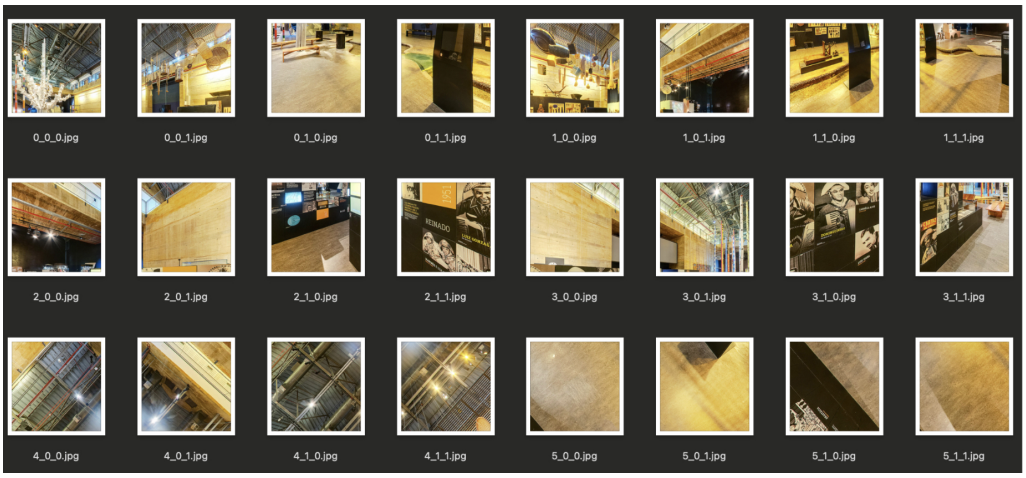


Figure 3. Example of a panorama as stored/used by the KrPano tool.

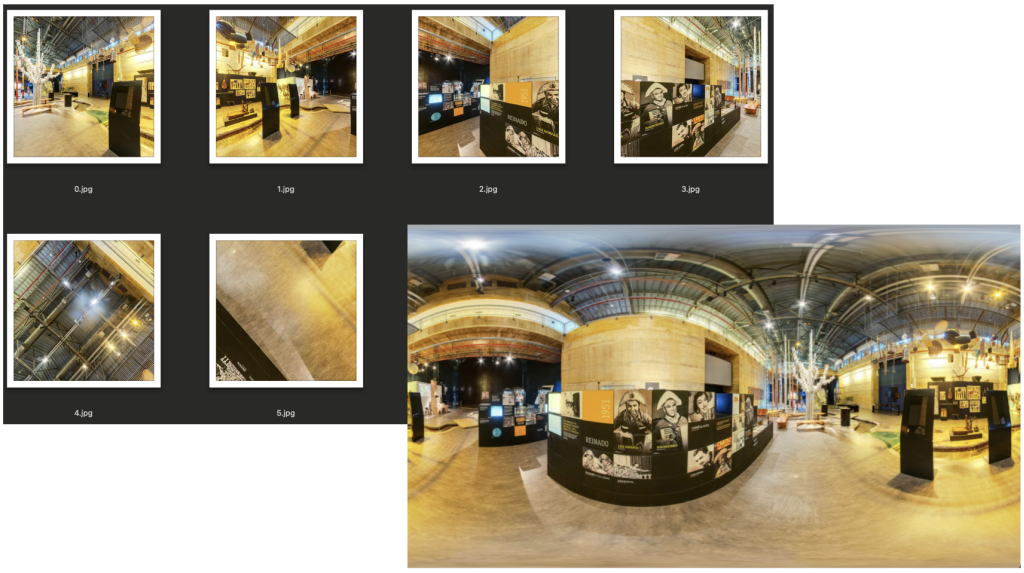


Figure 4. Images of the cubemap already "stitched" and then converted to the equirectangular representation.

### A. *Guided Tours*

Guided tours bring valuable attributes that can determine the museum visiting experience and, in this way, its social relevance. They strengthen the museum's relationship with people and have, as one of their main objectives, engaging in dialogue to promote debate and interaction with visitors. The experimentation of senses, emotions, and reflection is mostly stimulated by the guide's conversation with visitors and among visitors themselves [10]. Several museums already offer the option of having a museum guide accompany visitors, explaining about artworks and exhibition design. Drawing a parallel with the attributes of a real visit, it's possible for the same activity to be developed in a virtual environment in real time.

Unlike narration, a feature already available in some virtual tours, including the case study presented in this proposal, which is usually the same for all visitors, guided tours can provide an individualized experience where visitors interact directly with the museum guide, asking questions, clarifying exhibition-related matters, providing suggestions, and exchanging valuable information. Such interactions are not possible with prere-

corded guided tours. Virtual guided tours, with immersive interactive communication in the environment, also enable the dynamic to be carried out in groups, with people from different locations. This can optimize the service provided by the guide, who can accommodate more visitors' demands, and visitors, in turn, have the advantage of interacting with others during their visit, making the experience even more enriching and immersive.

### *B. Education and Learning*

Virtual tours are still underexplored in the educational field, but according to Pinto [11], they offer an alternative to physical visits. The author suggests that virtual museum tours can be an option for visits to spaces that may sometimes be geographically distant from schools or provide solutions to temporal, logistical, and economic issues. Pinto also highlights that virtual museum visits have positive effects on students' learning levels and motivation, and they allow for innovative pedagogical practices, such as interdisciplinary approaches.

Thus, the project proposed in this work could contribute to education by allowing teachers to act as guides in a virtual museum environment, presenting lessons to a group of students who may not be in the same geographic location as each other or the visited museum. In this virtual visit, the teacher can provide educational details while students can navigate the environment simultaneously, offering the possibility for students to have a different perspective from the presenter's, fostering curiosity and engagement. The teacher can receive real-time feedback and answer questions. Students can explore the museum in their own way, promoting a sense of freedom similar to a real-world experience.

Falk & Dierking [4] observed in their research that interactions among social groups in museums are more important for learning than an individual's solitary interaction with exhibits. Dialogues about experiments and exhibitions can significantly enhance learning and the process of constructing shared meanings.

According to LSR Guimarães [12], people learn differently in times of digital convergence. The meaning of "knowing" has changed; instead of being able to remember and repeat information, it is more important to be competent in searching for and using information. Therefore, it is interesting for students, in their learning environment, not to be mere spectators but active participants in their learning process. Participation can be supported by real-time audio and video communication with the teacher during a virtual museum visit, turning it into an extracurricular or complementary activity. This allows students to learn better through discovery, personal exploration, or collaborative exploration.

Despite the widespread popularity of distance education and virtual educational environments in Brazil, there is still no option within the virtual tours studied throughout this work to have real-time audio and video interaction between the teacher and students during a guided museum visit. In this sense, the proposed solution stands out as a facilitator that eliminates the need for additional software in the virtual teaching and learning process.

As it stands today, the teacher must be connected with their students in a video conferencing environment, such as Google Meet, and simultaneously present the content of the virtual tour. Even if audio and video communication is possible in this alternative environment, students still lack the autonomy to explore the desired path, view from their own perspective, and create questions based on their own search and curiosity. Even when multiple tools are used to obtain the desired communication resources, the presenter's viewpoint always prevails. Therefore, the proposal is not just about real-time communication but also about a differentiated and innovative way to immerse in the studied environment.

### *C. Gamification*

Gamification can be defined as the use of game elements in other contexts to create a gaming experience and increase engagement [13]. It can also be understood as a form of game-based learning [14]. Gamification can be seen as the creation of a space where participants can explore, interact, and discover what is meaningful to them, reflecting on their own experiences and transformation [15].

Considering that games and gamification in museums are seen as a trend in experience design [16], and again, from an educational context, innovative solutions are needed to develop attractive ways of teaching and learning within museums. While gamification and games are already being used in museum contexts to create more interactive and engaging experiences and become part of the museum's educational mission, there are still challenges in understanding the possibilities of approaching and applying gamification in this context [13].

Implementing communication between visitors, in a gamified environment, can enrich the learning process already inherent to gamification. By adding new features to the gamified visitation process in a virtual tour environment, such as the possibility of audio and video communication, it is possible to think of new ways of developing, for example, a multiplayer environment with avatar and profile creation personalized, thus expanding the possibilities of exploring collaborative and more fun learning processes.

### D. Participatory Curation

So far, this paper has focused on the visitor's museum experience and how it can be enhanced through the proposed solution. However, this solution can be useful for museum professionals and those involved in a specific museum as well. Looking at the internal dynamics of a museum, this solution can be applied from the early stages of exhibition creation, even in the planning phase, such as curation.

Research on participatory curation in a physical space has already been explored, although it is an uncommon practice [17], as in the case of the Dja Guata Porã exhibition at the Museum of Art in Rio (MAR). Baker discusses how the exhibition was created by external curators invited to the show, and how, based on an understanding of participatory curation, the exhibition involved its subjects - indigenous people - to collaborate with the curatorial team in constructing the exhibition, from creating artworks to deciding how they should be displayed in the gallery.

The proposed solution in this article allows curators and artists from different geographical locations to discuss exhibition design, narrative, and curation of artworks in real time, with a faithful reproduction of the environment where the exhibition will take place. This planning allows for greater possibilities for museums and their curatorial processes. Artists from various countries can be involved in the planning and creation of their exhibitions through participatory curation, and curators can virtually gather to develop various exhibition projects.

Participatory curation is just one example of the various possibilities in which museums and cultural exhibitions can benefit from the solution presented in this work. Whether in the planning, review, meetings, institutional presentations, training of professionals and exhibition guides, improvements in museum environments, exchange of experiences among museums, curators, artists, professionals, institutions, and more, this solution can be a valuable tool for all professionals involved in the process of preserving memory and disseminating art.

## VI. Conclusion

In this paper, we present the implementation of an innovative solution that enables real-time communication among visitors in a virtual museum tour. By conducting a case study using the virtual tour of the Museu Cais do Sertão, we were able to develop and test a solution that has the potential to enhance the immersive experience of virtual tour visitors, contributing to the improvement of experiences offered by museums and cultural spaces today.

Using A-Frame and Networked A-Frame, both open-source software, and employing Javascript, we created a multi-user experience where visitors to a digital museum can interact and engage in verbal communication throughout their visit. Including the ability to select specific environments, visitors can only hear those who are in the same scene, just like in a real-life visit.

The proposed solution involves the use of audio, with the possibility of video communication as well, within the virtual museum environment, and can be applied in various contexts, as presented in the possible scenarios. Based on preliminary tests conducted by the authors, the solution has shown promise for improving the experience and immersion in VR in the context of museum visits.

Visitors can come closer in a virtual visit to the real-world experience, particularly in terms of communication, allowing for idea exchanges, debates, teaching and learning, or simply for the feeling of companionship, as is typically experienced in a real visit. It is possible to hear the people around you and their reactions, influencing and being influenced, enhancing social interaction and making the virtual museum visit much more engaging and akin to a real visit.

As a proposal for future work, it is important to conduct user tests to validate the project and assess gaps to be explored, aiming to refine the idea. Tests can be conducted at different types of museums and with various users to compare the experiences of diverse visitors and how immersion occurs in different situations. Solutions related to the accessibility of individuals with total or partial disabilities, whether auditory, visual, among others, must be considered, and improvements for any limitations that may arise during the user testing process should be examined.

It is also interesting to conduct load tests with the goal of measuring the maximum number of users supported in each room by the Networked A-Frame. Additionally, other features may be developed in the future, such as audio moderation in rooms, indication of the number of people present in each room at a given moment, and other forms of communication between visitors (text and video chat, for example).

The scripts developed to enable this proof of concept are available in the following repository: https://github.com/enhancedvirtualtour/proof-of-concept.

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