TÉCNICO LISBOA

Asynchronous Collaborative Art Creation

Ana Cláudia Madeira David

Thesis to obtain the Master of Science Degree in

Computer Science and Engineering

Supervisors: Prof. Augusto Emanuel Abreu Esteves
Dr. Stuart James

Examination Committee

Chairperson: Prof. Rui Filipe Fernandes Prada
Supervisor: Prof. Augusto Emanuel Abreu Esteves
Member of the Committee: Prof. Frederic Fol Leymarie

June 2023

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Acknowledgments

I would like to thank my family, especially my parents, for their support and encouragement over the years. They have always been there for me and without whom, this work would not have been possible.

To my second family, Tuna Mista do Instituto Superior Técnico (TMIST), my heartfelt thanks for the countless nights of "*folia*" that we shared. I am immensely proud of how much we have grown together and the unwavering support we have for each other.

To my supervisors, Prof. Augusto Esteves, Dr. Stuart James and Prof. Daniele Giunchi, my sincere gratitude for their invaluable insights and guidance. Their mentorship was crucial for the progress and quality of this project.

To my close friends, thank you for your belief in me throughout this challenging journey. Your presence and encouragement have been a source of motivation and inspiration.

Finally, I am immensely grateful to the individuals who participated in my research. Your willingness to contribute has been incredibly helpful to the completion of this work.

Thank you all for your invaluable contributions.

Abstract

Collaborations in art can lead to the creation of innovative content and potentially generate new art movements. However, traditional collaboration methods often pose challenges, as they require artists to work within a shared physical space or coordinate themselves using inconvenient asynchronous methods. Furthermore, collaborative art projects may encounter downsides that do not exist in individual art creation. Artists usually are forced to align their ideas and have a deep understanding of each other's perspectives, which can be a challenging process. To address these challenges, we developed a Virtual Reality application offering an alternative approach for contributing artists. This system incorporates version control as a means to encourage idea exploration and minimize creative conflicts during the collaborative process.

Through user testing, we evaluated the Virtual Reality environment created and gained valuable insights into its potential benefits. Our findings revealed similarities between the Virtual Reality environment and a traditional real-life setting in terms of the level of immersion and engagement experienced by artists. These results show that Virtual Reality can provide an adequate environment for asynchronous collaborative art creation. Moreover, the utilization of Virtual Reality positively influenced users' sense of ownership over the creative process and facilitated the exploration of new ideas. Our research not only addresses the challenges posed by usual collaboration methods but also contributes to the advancement of asynchronous collaborative art practices.

Keywords

Art Collaboration, Asynchronous Collaboration, Version Control, Virtual Reality.

Resumo

Colaborações em arte podem levar à criação de conteúdo inovador e potencialmente gerar novos movimentos artísticos. No entanto, métodos tradicionais de colaboração frequentemente apresentam desafios, uma vez que exigem que os artistas trabalhem num espaço físico partilhado ou se coordenem através de métodos assíncronos inconvenientes. Além disso, projetos de arte colaborativa podem enfrentar desvantagens que não existem na criação individual de arte. Os artistas geralmente são obrigados a alinhar ideias e ter uma compreensão profunda das perspetivas dos outros, o que pode ser um processo desafiante. Para enfrentar estes desafios, desenvolvemos uma aplicação de Realidade Virtual que oferece uma abordagem alternativa para artistas colaboradores. Este sistema incorpora controlo de versões como um meio para incentivar a exploração de ideias e minimizar conflitos criativos durante o processo colaborativo.

Através de testes de utilizadores, avaliámos o ambiente de Realidade Virtual criado e obtivemos observações valiosas sobre os seus potenciais benefícios. As nossas descobertas revelaram semelhanças entre o ambiente de Realidade Virtual e um ambiente tradicional de vida real em termos do nível de imersão e envolvimento experienciado pelos artistas. Estes resultados demonstram que a Realidade Virtual pode proporcionar um ambiente adequado para a criação de arte colaborativa assíncrona. Adicionalmente, a utilização de Realidade Virtual influenciou positivamente o sentido de propriedade dos utilizadores sobre o processo criativo e facilitou a exploração de novas ideias. A nossa pesquisa não aborda apenas os desafios apresentados pelos métodos habituais de colaboração, mas também contribui para o avanço das práticas de arte colaborativa assíncrona.

Palavras Chave

Colaboração de Arte, Colaboração Assíncrona, Controlo de Versões, Realidade Virtual.

Contents

List of Figures

List of Tables

Acronyms

2D	Two-dimensional
3D	Three-dimensional
CEO	Chief Executive Officer
FBAUL	Faculdade de Belas-Artes da Universidade de Lisboa
HMD	Head-mounted Display
IST	Instituto Superior Técnico
LAN	Local Area Network
RL	Real-life
SUS	System Usability Scale
SVR	Social Virtual Reality
UCL	University College London
UEQ-S	User Experience Questionnaire Short Version
UI	User Interface
VR	Virtual Reality

1

Introduction

Contents

The human activity of art creation involves creativity and the expression of the world through the artist's unique experiences. Artworks are also shaped to convey meanings and concepts, serving as a form of communication. These creations of art can be developed individually or in collaboration with others. Collaboration in different contexts has been studied to lead to better learning, the development of cognitive skills, and generate innovative creations. [1, 2]

Collaboration in art is not a new concept, and it has been executed in various ways depending on the artists and their objectives. [3] Art collaborations often result in fresh perspectives, as artists contribute their skills and ideas. For instance, one of the most famous art collaborations, between pop artist Andy Warhol and graffiti artist Jean-Michel Basquiat produced several art pieces, including the popular artwork *Olympic Rings* in 1985. [4] Similarly, the German couple Bernd and Hilla Becher collaborated on black-and-white photography of industrial architecture for 50 years, with equal ownership and no division of tasks or photo identification. [5] These successful collaborations worked because the artists understood each other's objectives for the artwork and allowed for the unpredictability of their collective imagination.

However, collaborative art also presents challenges, particularly regarding ownership of the resulting artwork. In many cases, there is ambiguity regarding who owns the intellectual property rights of the artwork, leading to legal disputes and financial issues. [6–8]

Despite a history of successful partnerships, the creation of art is mostly associated with introspective and personal endeavors. Like art, Virtual Reality (VR) technology has also been associated with an individual experience, immersing the user in an artificial world and disconnecting from the physical one. [9, 10] However, VR has demonstrated positive results in enhancing creativity [11, 12] and there is a growing interest in using this technology for strengthening relationships and co-creation, particularly through Social Virtual Reality (SVR). SVR platforms are unique social interaction spaces that create immersive experiences for users, enabling them to build interpersonal connections through interactive VR activities and various forms of communication. [13–15]

Previous applications of VR art collaboration have often followed the SVR approach, providing platforms for real-time co-creation and sharing. However, with these applications and the success of VR artwork, [16] currently, these methods of collaboration often force artists to conform to a single artistic direction to complete an artwork, leading to unsatisfying outcomes and collaborations. [17–19] This approach highlights a gap in social and community-based art collaborations that respect the diverse styles, ideas, and individuality of participating artists in the final artworks.

With this project, we aim to bridge this gap by proposing an asynchronous VR art application that allows artists to collaborate and exchange ideas while preserving individual creative freedom. This solution acknowledges the increasing growth of artist communities in social media and digital art movements that actively engage in asynchronous art collaborations. [20, 21]

To accommodate multiple ideas and art styles, this solution features a version control system that

enables artists to experiment with various versions of their artwork, providing the option to test different ideas and iterate on their work. This type of version control, which allows for the storage of multiple instances of the same piece, is only achievable in digital artwork and not possible in traditional painting, where artists must work over their previous work or recreate an inexact copy of the piece.

Overall, this solution aims to establish collaborative spaces that preserve the benefits of solo artistic work while fostering a supportive environment for artistic expression. By combining the flexibility of asynchronous collaboration and version control, this approach offers a new way for artists to collaborate while enabling them to explore new ideas, experiment with different versions of their artwork, and respect each other's artistic freedom in the collaborative process.

The evaluation process involved conducting user tests, where participating artists provided feedback, interacted with the VR environment, and shared their perspectives on the platform's features and capabilities. By analyzing these interactions, the collected data informed the development and refinement of the solution.

1.1 Research Questions

The solution presented in this work aims to explore asynchronous art collaboration through a VR application. The development of the application and its subsequent evaluation were guided by the following research questions:

RQ1: Does the immersion and engagement of Virtual Reality provide an adequate environment for asynchronous collaborative art creation?

RQ2: How does the use of Virtual Reality for asynchronous collaboration impact artists' sense of ownership over the creative process? To what extent do artists explore different ideas for an art piece?

1.2 Hypothesis

To gain insights into collaborative art creation and the potential role of VR in this context, a questionnaire was administered to sixteen individuals who had prior experience in art collaborations.

The closed questions asked during the interviews and their corresponding answers are summarized in Table 1.1. The questions focused on various aspects of collaboration in art, including the perception of quality with collaboration, feelings of insecurity about collaborating on art, preferences for collaborating with others or working alone, expression of personal style in collaborative projects, and the impact of collaboration on art production.

Of this group, six were currently or previously enrolled in an art degree in painting, while the other ten engaged in painting or drawing as a hobby, with half of them having other types of arts degree

Table 1.1: Table with interviewees' answers about their experiences of collaboration in art, median and standard deviation of the responses.

Closed question	Median	SD
The results of art are better with collaboration	3.00	0.93
Art collaboration creates fresh ideas	4.00	1.06
I feel/would feel insecure about collaborating with someone on my art	2.00	1.33
I like to collaborate with other people on art	3.00	0.96
I prefer to work alone on my art projects	4.00	1.28
I like that my art projects have my style clearly expressed	4.00	0.81
I would make more art if I collaborated with others	3.00	1.42

Note: Scoring from 1 (completely disagree) to 5 (completely agree)

background. Among the interviewees, 56% reported having used VR, and from this group with VR experience, only 33% had previous experience with VR painting apps such as Tilt-brush, A-Painter, Painting VR, or similar platforms.

When asked about their motivations for collaborating in art, interviewees provided diverse responses, including resource management (P13: "(...) if it's a massive project with a time limit.", P1: "It takes less time and energy."), sharing of ideas (P11: "The more people, the more ideas, the more that we can explore a subject in ways that I wouldn't have on my own.", P2: "Being each others' catalyst when hitting mental blocks and the opportunity to examine multiple perspectives at once."), entertainment (P16: "It's more fun and inspiring.", P15: "Some of the work I've collaborated on was usually just for fun and to see what would happen with our meshed, different types of methods. Other times it was just satisfying to see a finished product, all from our hands.") and different skill interaction (P8: "I can specialize in a certain aspect of the art piece.", P9: "If it's a multidisciplinary project.", P10: "Create a project beyond my individual capabilities.").

These interviews provided valuable information that served as the basis to formulate hypotheses for this study. The hypothesis serve as predictions for the outcome of the study and provide a clear direction for addressing the research questions. The validation or refutation of these hypotheses will be determined through data collection and analysis, which will be presented later in this work in Section 5.3.

RQ1: Does the immersion and engagement of Virtual Reality provide an adequate environment for asynchronous collaborative art creation?

H1.1: While creating art in Virtual Reality, the levels of attention and emotional connection achieved are higher than in real-life art creation.

H1.2: In Virtual Reality, the recognition of asynchronous collaboration is easier for participants, as compared to the real-life scenario.

RQ2: How does the use of Virtual Reality for asynchronous collaboration impact artists' sense of ownership over the creative process? To what extent do artists explore different ideas for an art piece?
H2.1: Artists prefer to paint in specific sections of their artwork, creating their own working areas.
H2.2: The number of new branches created will increase over the evaluation sessions.
H2.3: The mean number of painting strokes is expected to be higher in newly created branches compared to the asynchronous collaborative branch.

1.3 Thesis Outline

This document is divided into six chapters and several appendices about the following contents:

- **Chapter 1 Introduction**: Overview of the problem being addressed and outline of the research questions and hypothesis explored.
- **Chapter 2 Related Work**: Analysis of previous research and other work relevant to the topics addressed.
- **Chapter 3 Proposed Solution**: Description and explanation of the proposed system.
- **Chapter 4 Implementation**: Information about the system's implementation and features.
- **Chapter 5 User Evaluation**: Description and interpretation of the evaluation's results.
- **Chapter 6 Conclusion**: Main takeaways from the project and potential future work.
- **Appendix A Collection of User Artworks**: Presents all the artworks created by the users during both user tests.
- **Appendix B First User Test - Real-life (RL) and VR Environments Questionnaire**: Questionnaire used to evaluate the RL and VR environments in the first user test.
- **Appendix C First User Test - Branching Interface Preference Questionnaire**: Questionnaire focused on gathering preferences for the system's branching interface in the first user test.
- **Appendix D Second User Test - Demographic and Immersion Tendencies Questionnaire**: Questionnaire used to collect demographic information and assess immersion tendencies in the second user test.
- **Appendix E Second User Test - Painting Session Satisfaction Questionnaire**: Questionnaire used to evaluate user satisfaction regarding the painting sessions in the second user test.
- **Appendix F Second User Study - Additional Table**: Additional results of the evaluation from the second user test.

2

Related Work

Contents

To comprehensively investigate the research questions presented in Section 1.1, we reviewed relevant literature on different styles of collaboration in art in Section 2.1. Following this, we explore the potential of asynchronous interactions in creating new art pieces in Section 2.2. From this understanding, we examined various approaches that use digital tools, firstly in collaborative VR art in Section 2.3, and secondly for version control of art and Three-dimensional (3D) models in Section 2.4.

2.1 Collaboration in Art

Art collaborations can take various forms, and one notable artistic movement centered around collaboration was Dada or Dadaism. Emerging in early 20th-century European art, Dada was based on the spirit of performance, play, and collaboration. Cabaret Voltaire was the artistic nightclub in Switzerland that represented Dada's characteristics the most. With an unusual fusion of theater, poetry, and art exhibitions, artists collaborated in anti-war performances amid World War I. [22] Only four years after Cabaret Voltaire's opening, the First International Dada Fair was held in Berlin and featured over two hundred artworks. (Figure 2.1)

Another example of collaborative art in the early 20th century was the surrealistic game known as *cadavre exquis*. (Figure 2.2) This collaborative game often engaged a small number of artists who would contribute to a drawing, collage, or sentence with no knowledge of what the others had already done. The outcome was often a spontaneous and unpredictable artwork that integrated the distinct styles and ideas of each participant. According to André Breton, one of the principal founders of Surrealism, what initially began as a lighthearted activity, eventually evolved into a playful and enriching experience, opening up new artistic possibilities through mutual collaboration. [23]

In contemporary art, collaboration continues to be a significant phenomenon. Brian Sherwin, an

Figure 2.1: The First International Dada Fair, Berlin, 1920.

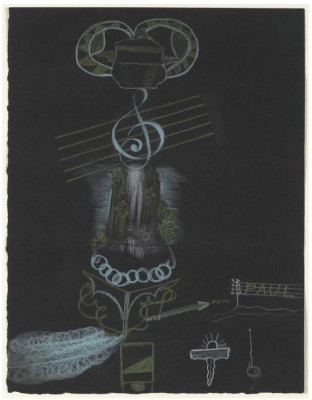


Figure 2.2: *Cadavre exquis*, a Surrealist collaborative art technique, made in circa 1930 by artists André Breton, Nusch Eluard, Valentine Hugo and Paul Eluard.

Figure 2.3: Still image from SUPERFLEX's *Flooded McDonald's*, 2009. A critique on mass-production of food and the role of large multinational companies in climate change.

Figure 2.4: Chim↑Pom visiting the exhibition *Don't Follow the Wind* in Fukushima. A collaboration of the group and a dozen international artists that only a small number of visitors can see until the nuclear contamination is cleaned up.

American art critic, described collaboration in art as the "ultimate test of placing your ego aside in order to work toward a common idea". He also noted that creative conflict can arise in collaborative art, emphasizing the importance of mutual respect and trust among collaborators for successful outcomes. [24]

Curator and writer Ellen Mara De Wachter, after interviewing twenty-five collaborative groups, such as the Danish group *SUPERFLEX* and the Japanese group *Chim↑Pom*, concluded that these collaborative groups do not subscribe to the exaggerated appreciation of authorship and individuality. These are attributes that solo works are admired for and are unnecessary to present artworks with strong meanings. [25] (Figure 2.3 and 2.4)

2.2 Asynchronous Art

Asynchronous art not only allows artists to express themselves at their own pace, but it also has the potential to involve a much larger number of participants compared to synchronous art creation.

One notable example of asynchronous art is "The Johnny Cash Project", an online art project that invites participants to contribute to a crowd-sourced painted music video of "Ain't No Grave" by Johnny Cash, involving over 250,000 fans from 172 countries. [26] In this project, participants create and submit unique drawings that are then compiled and added as frames to the music video. (Figure 2.5) This form of collaborative art maintains individual expression while fostering collaboration, interaction, and connection between the fans of the deceased musician in an ever-evolving homage. [27]

Another example of asynchronous art is "The 1000 Journals Project", launched in 2000 by the artist Brian Singer. [28] This innovative project ended up reaching over 40 countries, resulting in a book, a feature-length documentary and multiple art exhibitions. The concept of the project involved leaving a

Figure 2.5: Screenshot of The Johnny Cash Project website showcasing a visualization of frames for the music video.

Figure 2.6: The 1000 Journals Project exhibition in San Francisco Museum of Modern Art (SFMOMA) in 2008.

thousand blank journals in public spaces with instructions for individuals who find them to contribute something and then pass the journal to another person. This project created a diverse and dynamic experience, with each participant adding their own unique perspective to the journals. (Figure 2.6)

These projects demonstrate examples of collaborative art that go beyond traditional synchronous methods. By allowing artists to express themselves without time constraints and with the possibility to involve a larger number of participants, asynchronous art projects open new possibilities for creativity, collaboration, and connection in the art world.

2.3 Collaborative Virtual Reality Art

The field of collaborative VR is one that is vastly researched, with a wide range of studies conducted in various fields, from general collaboration [29] to workplaces [30] and education [31]. In the context of VR art creation, there are several applications that enable artistic collaboration. In this section, we will discuss some of these applications, including Oculus Medium, MasterpieceVR, and Multi-A-Painter, as well as the provided features for collaborative VR art creation, and their respective levels of complexity and innovation.

One of the earliest examples of a collaborative VR art creation application is Oculus Medium, a digital sculpting software released for Oculus Rift in late 2016. [32] In 2017, with the release of version 1.2, it became the first major VR art software to offer multiplayer functionality. However, this feature was very limited, only allowing two users to connect and communicate in the same room, as shown in Figure 2.7. The connected users could see each other's artwork but were constrained to working on their art pieces, meaning they were not collaborating on the same artwork.

Another example is MasterpieceVR, released at the end of 2017 by Brinx Software, with the focus on synchronous painting and sculpting with other users. [33] In this application, users were able to chat

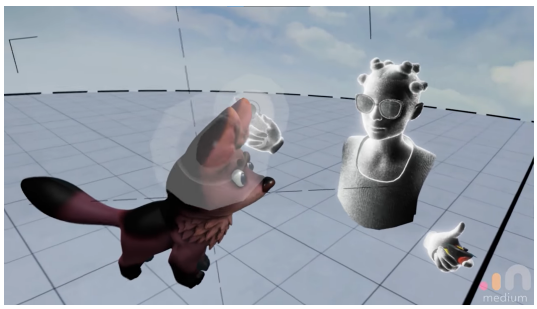


Figure 2.7: User giving feedback on a sculpture done in Oculus Medium.

Figure 2.8: Promotional image of MasterpieceVR multiplayer feature.

while working on the same art piece. To not disrupt the other person, each user had their view of the artwork. Jonathan Gagne, Chief Executive Officer (CEO) of Brinx, described it as "a virtual sandbox for friends or production teams to use. Creators can work together on a project, exchange ideas, give real-time feedback or teach a 3D modeling class in virtual reality". When interviewed on the purpose of the application, he said, "We wanted users in different locations to be able to walk into the same virtual room and begin cooperating on a project immediately in a highly productive and effective way. MasterpieceVR makes this possible" (Figure 2.8). MasterpieceVR required users to be online to collaborate synchronously, which could be a limitation for international teams. In 2019, MasterpieceVR was discontinued and replaced by Masterpiece Studio, but the synchronous collaboration feature remained.

Similar to MasterpieceVR, Multi-A-Painter is an open source extension of Mozilla's A-Painter application, where users anonymously collaborate by creating 3D paintings in real-time. [34] While the anonymity can be liberating for users, it can also hinder communication and collaboration towards specific goals.

While collaborative VR art has seen advancements in recent years, there are still limitations that can be addressed to make it more appealing, such as real-time collaboration on the same artwork, providing offline and asynchronous collaboration options, and improving communication tools within the VR environment.

2.4 Art and 3D Model Version Control

Version control for art emerged in the context of storing individual artworks and virtual heritage. More recently, museums and curators have become interested in this technology and opened the possibility of creating instances of artworks to represent changes in time and enable creative challenges for artists. [35, 36]

One system that aligns with this trend is Open3D, which facilitates the collaborative curation of large-scale city models. It supports real-time collaborative editing and updating of 3D models of buildings for

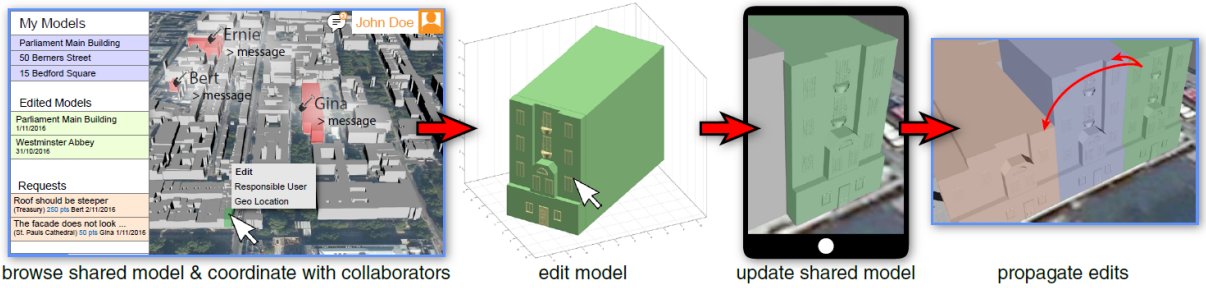


Figure 2.9: Pipeline of Open3D procedural edits.

synchronous users. [37] When users make changes, they can choose a model, edit it in the separate Open3D Editor, and update the Open3D Browser. (Figure 2.9) These components communicate with a server to retrieve or update models, while editing conflicts are avoided through a locking mechanism. The procedural modeling changes are saved as the edit history of each building, and these models can be reused for modeling similar buildings.

Graphic design projects were also in need of version control, and in 2021, SnowFS was introduced as an open-source version control software specifically designed for graphic files. [38] It is a lightweight application that enables backup, storage and synchronization of projects on different devices, while providing access to different versions of the project. Built around the idea that projects go through various interactions and different ideas, SnowFS has native cloud capabilities tailored for Two-dimensional (2D) art and 3D modeling programs, mainly the 3D modeling program Blender [39]. The application that serves as User Interface (UI) of SnowFS, called Snowtrack, produces a visualization of the project evolution and provides interactive thumbnails of the working versions, as shown in Figure 2.10.

With the increase in museum digitization and the creation of 3D model libraries [40], the implementation of version control has been predominantly used for historical artifacts and their several stages of modeling. The underlying technology behind many of the version control methods previously mentioned is Merkle trees. The tree is constructed by recursively hashing pairs of nodes until only a single hash remains, called the root hash or the Merkle root. Each leaf node in the tree represents a piece of data, and each non-leaf node represents the hash of its child nodes, as shown in Figure 2.11. The usage of hashes allows for data separation and integrity checks. [41] By using Merkle trees, version control systems can detect and prevent conflicts that arise when merging different versions during collaborative editing, track changes made by individual users, and maintain the consistency of the data across different versions.

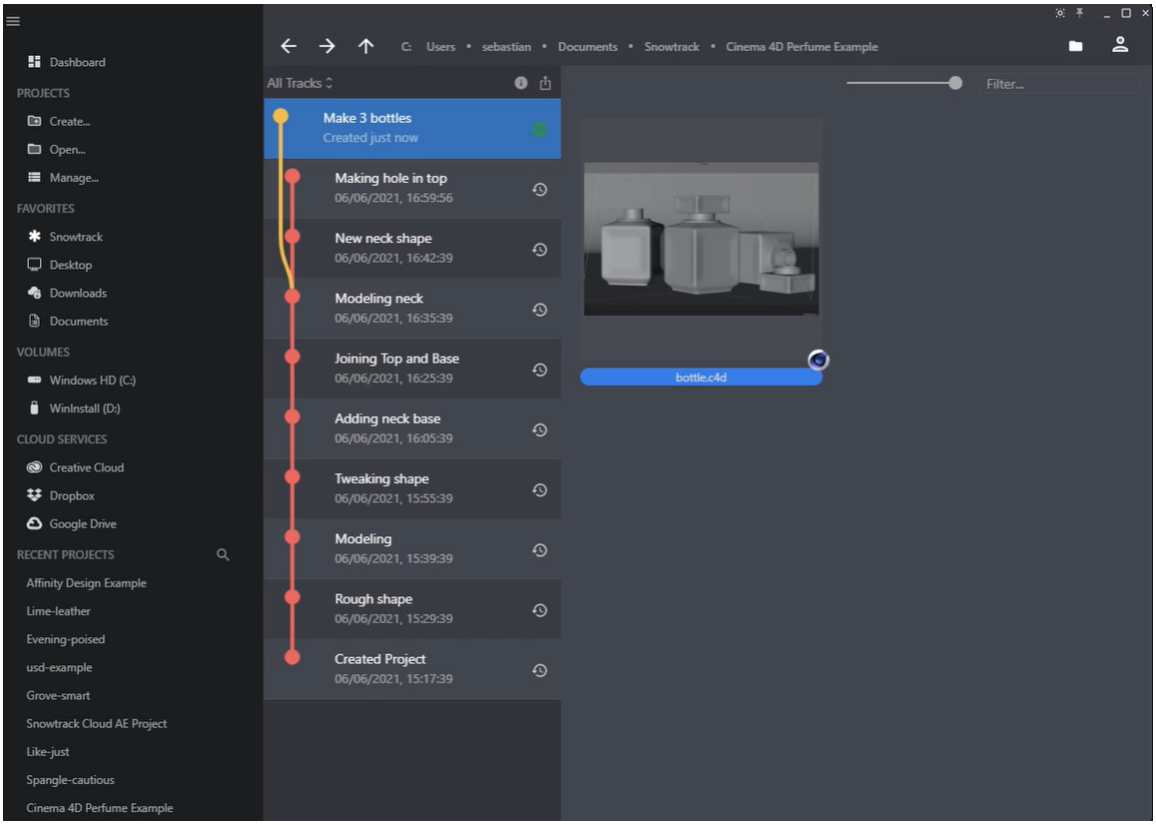


Figure 2.10: Snowtrack's visualization of a 3D project timeline.

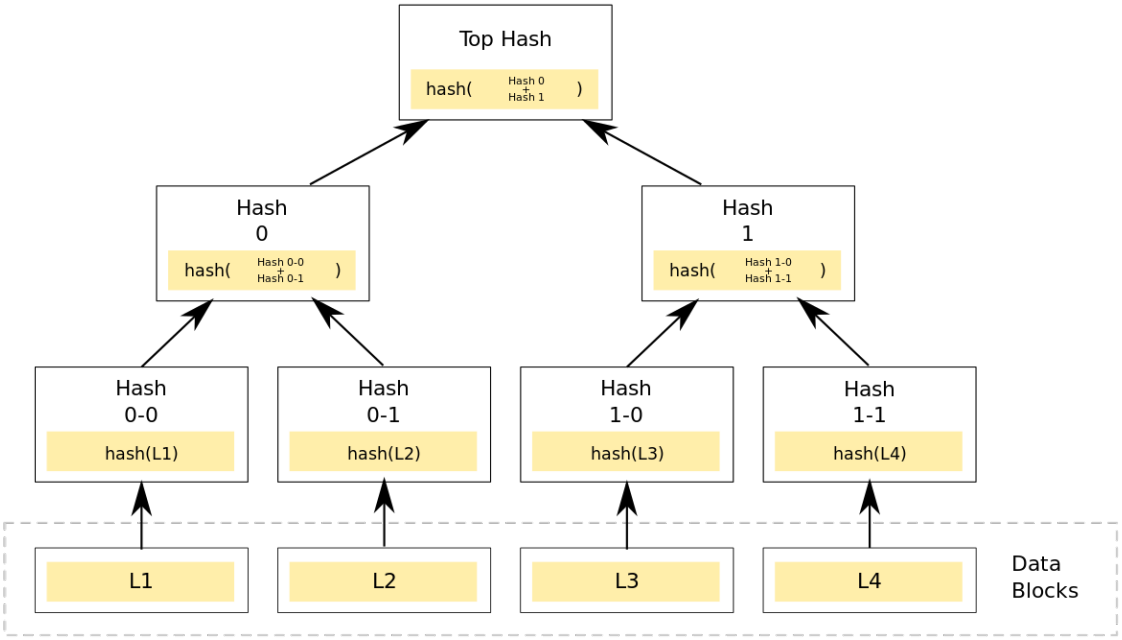


Figure 2.11: Binary Merkle tree. Non-leaf nodes' hash values are the concatenation of children's hash values.

3

Proposed Solution

Contents

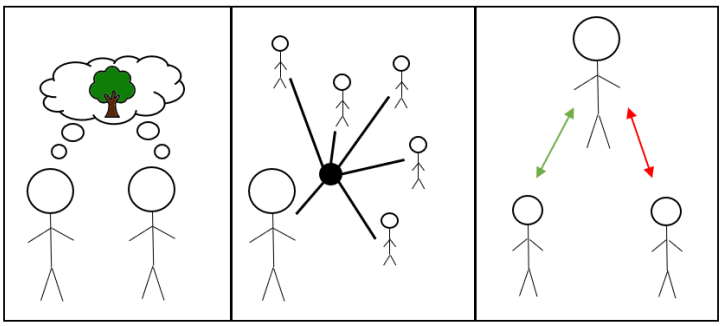


Figure 3.1: Representation of the three contexts in which collaboration in art applies. (Left) Group, (Middle) Community, (Right) Hierarchical.

The proposed solution aims to facilitate non-invasive collaboration that does not impose pressure on a single concept or version of an artwork.

To address the research questions, we implemented the solution on a single type of art, and chose to do it in VR to allow collaboration between geographically distant users and to provide a more immersive and interactive environment. Among the different types of art, 3D painting was chosen because of its relatively low interface requirements and easy adaptation to VR. This approach also allows for a lower VR skill requirement for users while maintaining a high level of artistic skill. However, it is important to acknowledge that the chosen approach for creating artworks requires physical space and movement. This design choice may limit the accessibility and convenience of the collaborative art creation process. Exploring alternative design choices could potentially mitigate this limitation and make the process more accessible and convenient for a wider audience.

Collaborative art projects can take on different contexts as discussed with artists in Section 1.2. These contexts include: a group of artists who are interested in producing an artwork asynchronously with defined objectives or themes, an artist who creates a base for an art piece and releases it publicly for a community to participate, or an artist who is hierarchically superior to others where the development of an art piece needs their approval. (Figure 3.1) To develop the proposed solution and perform the subsequent evaluation, the contexts presented were considered. The focus selected for this project is the scenario of a group of artists interested in producing an artwork asynchronously with a general objective or theme.

To inform the development of our solution, we conducted research on existing art creation software for VR, evaluated their features, and gained an understanding how art collaboration usually works through the artists' interviews. Based on this research and the insights obtained, we compiled a list of requirements (Section 3.1). Considering these requirements, we also present the architecture of our solution (Section 3.2).

3.1 Requirements

From the interviews with artists in Section 1.2, the following requirements for the VR application were gathered:

- Basic painting features in a VR environment with the use of a Head-mounted Display (HMD) and hand controllers;
- Range of materials and colors to choose from;
- Visualization of the artwork in 3D perspective;
- Control of the painting, with undo and redo actions;
- Facilitation of collaborative art creation by allowing users to:
  - Invite others to participate in their collaborative artwork;
  - Store multiple versions of an artwork throughout the various iterations;
  - Track progress of the project and contributions from each user;
  - Work on the same project without requiring interaction with each other.
- Enable users to experiment with different versions of the project, emphasizing their ability to express ideas without overriding previous work.

3.2 Architecture

The proposed solution is an application[1] that facilitates asynchronous collaboration for art creation. To meet the requirements identified in the previous section, the proposed system utilizes two existing technologies: Ubiq and Open Brush. Figure 3.2 illustrates how Ubiq provides a platform for creating multiple rooms, each incorporating the mechanics, features and UI of Open Brush to enable collaborative artwork creation. These technologies communicate with the local device storage, allowing users to manage and save their artworks and related data. The application saves data in a version control tree structure, allowing users to start a session at any saved point and add from it.

Both Open Brush and Ubiq were developed using Unity, which is a cross-platform game engine that supports the creation of 2D and 3D experiences for multiple platforms, including VR devices. [42] Unity's active community of developers from different levels and backgrounds provides a vast library of tools and assets, making for an efficient implementation of our proposed solution. The necessary scripting was performed using the C# programming language, which is commonly used in Unity.

[1] https://github.com/aclaudiadavid/Asynchronous-Collaborative-Art-Creation

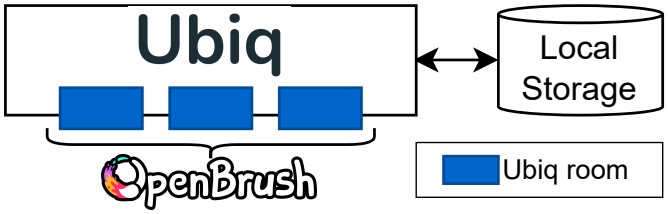


Figure 3.2: Proposed solution's architecture.

Figure 3.3: Ubiq's avatars representing users in a VR environment.

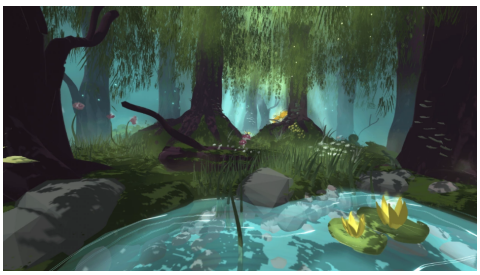


Figure 3.4: VR 3D painting made with Open Brush.

3.2.1 Ubiq

Ubiq is an open-source toolkit designed to simplify the construction of SVR systems. [43] Ubiq has a server that maintains rooms with a peer system, providing standard SVR features such as avatars, voice chat, and connection management. (Figure 5.13) Its flexibility and adaptability makes it an ideal tool for developers seeking to create collaborative VR experiences.

Our proposed solution leverages Ubiq rooms to provide a social environment for asynchronous collaborative art creation. Although Ubiq is primarily designed for real-time synchronous collaboration, we have adapted it to create and host rooms for our proposed solution. While we do not utilize its real-time features, Ubiq still serves as a reliable platform for managing collaborative art creation and preserving the various states and iterations of artworks. Implementing Ubiq in our proposed solution meets the requirements for user participation in collaborative work and the management of artwork iterations.

The Ubiq version used in our solution is version 0.1.1, which can be found in the University College London (UCL) Ubiq GitHub repository. [44]

3.2.2 Open Brush

Open Brush is a 3D painting VR application that originated from the open-source code of Tilt Brush, a previously discontinued application by Google. [45] With Open Brush, users can create paintings in a room-size 3D space with the freedom to choose from various colors, brushes, and sizes. (Figure 3.4) Since January 2021, Open Brush has added several features, including some experimental and alternate builds, and it is available on different platforms.

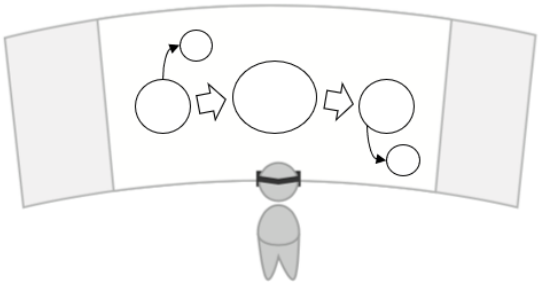


Figure 3.5: Conceptual illustration of the user's perspective of the saved art instances in a version control tree.

Open Brush's features meet the requirements for a VR environment designed for painting with a HMD and hand controllers. Being open-source and having an active community provides the necessary flexibility to easily modify and adapt it during the implementation of our proposed solution.

To implement our solution, we used Open Brush version 0.3.0 [46], which requires SteamVR [47] and Unity version 2019.4.25f1 [48]. This version of Open Brush offers a comprehensive set of painting tools and features that allowed users to create and manipulate their artworks.

3.3 Version Control Tree

In order to support asynchronous collaboration in the VR application, we implemented a version control tree with a UI that tracks the progress of art projects made in the application. (Figure 3.5) This allows collaborators to make changes without overwriting each other's work and facilitates the ability to revisit previous versions. With the version control tree, we aimed to provide more freedom and exploration in the creative process.

The version control tree is a hierarchical data structure that organizes the various versions of a project. It comprises a root node, representing the first saved version of the project, and a set of parent-child relationships that specify which version every non-root version is expanded from.

In our proposed solution, each time a user saves an artwork, a new instance is created, either as a root node or as a child of a previous instance. By using a version control tree, users can work from any previously saved instance of the artwork through the ability to create multiple branches.

A branch refers to a path of subsequent instances from the first saved point in the project until a leaf/terminal instance. In the version control tree, a leaf or terminal instance refers to a node with no child nodes, indicating the end of a branch, as shown in Figure 3.6. A new branch is created every time an artist continues an instance that is not a terminal instance. Finally, a new project is presented by a new root of a version control tree.

Our solution incorporates a custom-made version control tree inspired by Merkle tree structures. We made the deliberate decision not to use a traditional Merkle tree implementation, as it allowed us to

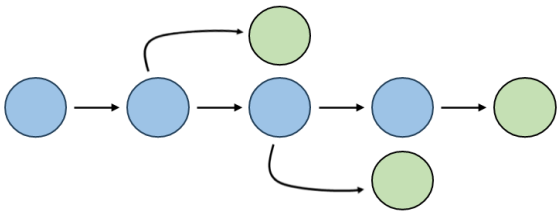


Figure 3.6: Example of version control tree with highlighted green leaf/terminal nodes. In this tree there are three branches.

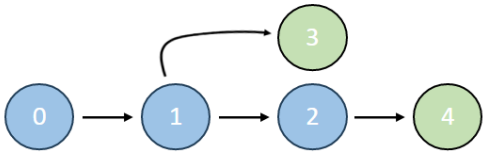


Figure 3.7: Example of version control tree with one root, five nodes, two branches, and highlighted green leaf nodes.

avoid complex merging processes and ignore security aspects that require hashing.

3.3.1 Creating the Version Control Tree

To create a new instance, the user paints and then saves the progress of the artwork. Each save action is treated as a new instance, without overwriting any previous saves. When the save action is received by the **HistoryManager** script, the **HistoryGraph** script is called to create the new instance.

The new instance is represented by an object of the class **Node**, which contains its identification and a list of the identifications of its children. Once the node is created, it is placed in the tree. If this is a new project and the tree is empty, the node becomes the root and a new project has been started. If this is not a new project, then this new instance becomes a new leaf, and its identification is added to its parent's list of children. The HistoryGraph keeps track of the current version tree, and every time a modification is made, the HistoryManager exports the HistoryGraph into a JSON [49] file.

The JSON file includes the number of nodes in the tree (*number_nodes*), the roots and the nodes with their identification and list of children. For example, to create a tree with one root, five nodes, and two branches, as illustrated in Figure 3.7, the corresponding JSON file would have the following structure:

```
{"number_nodes":5,
"roots":[0],
"nodes":
    {"0":{"id":0,"children":[1]},
    "1":{"id":1,"children":[2,3]},
    "2":{"id":2,"children":[]},
    "3":{"id":3,"children":[4]},
    "4":{"id":4,"children":[]}}
}
```

By storing the version control tree locally in a JSON file, we can preserve the entire history of the

project and make it available for visualizing and loading instances. This allows the user to navigate through the project's history and easily choose any previous instance to work from.

3.3.2 Loading the Version Control Tree

When the user requests to visualize the instances, the locally stored JSON file is loaded into the HistoryGraph. The HistoryManager then generates the UI for the graph, creating interactive blocks for each instance and connections between the nodes to depict the structure of the tree.

Using this visualization, the user can select a particular instance to load and continue working on. The HistoryManager sets the identification of the selected instance as the current open node, so that the next saved project has that instance as its parent. This allows the possibility for the user to branch out from any previous instance, creating a new branch in the version control tree and allowing for multiple branches to exist.

4

Implementation

Contents

Our system was designed to meet the requirements presented in Section 3.1, which were aimed at providing users with a virtual environment that facilitates asynchronous collaborative art creation. To achieve these goals, we developed our system in two iterations.

During the first iteration, we focused on integrating Ubiq into the Open Brush system, simplifying the Open Brush UI, and adding environment walls. This iteration was used in the first user test, which involved participants with artistic backgrounds comparing RL and VR environments for asynchronous collaborative art creation. Their feedback from the user test was relevant to refine the system for the subsequent iteration.

In the second iteration, we incorporated the feedback received from the first user test and added essential new features to the system for the second user test. The features included a timer, user identification, and extensive data collection. Additionally, the entire branching system was implemented, including a UI and the ability to save and load instances. These modifications played a vital role in the second user test, where users engaged in an asynchronous collaborative artwork creation process across multiple sessions to deepen our understanding of ownership and idea exploration within this environment and context.

4.1 First Iteration

After integrating Ubiq into the Open Brush system, we worked on simplifying the Open Brush UI, for a more user-friendly experience, and adding environment walls. These changes were made with the intention of preparing the system for the first user test.

4.1.1 First Iteration: Open Brush UI Simplification

In this iteration, our goal was to simplify the Open Brush UI, to accommodate users who may not be familiar with VR technology. We recognized that having a complex interface may be overwhelming for some users, and we wanted to ensure that they could easily navigate through the system. The original interface, as seen in Figure 4.1, contained numerous features per menus, with 9 pages of brushes to navigate. To achieve our objective, we focused on retaining only the essential tools, as shown in Figure 4.2. We also reduced the number of brushes, removing those that were similar to other brushes or intended for 3D sculpting, resulting in less than 3 pages.

4.1.2 First Iteration: Environment Walls

To standardize the user testing environment and ensure consistency among participants, we added environment walls to create a fixed virtual testing area with dimensions of 2.30m x 2.30m. (Figure 4.3)

Figure 4.1: Original Open Brush Tools UI.

Figure 4.2: Simplified Open Brush Tools UI.

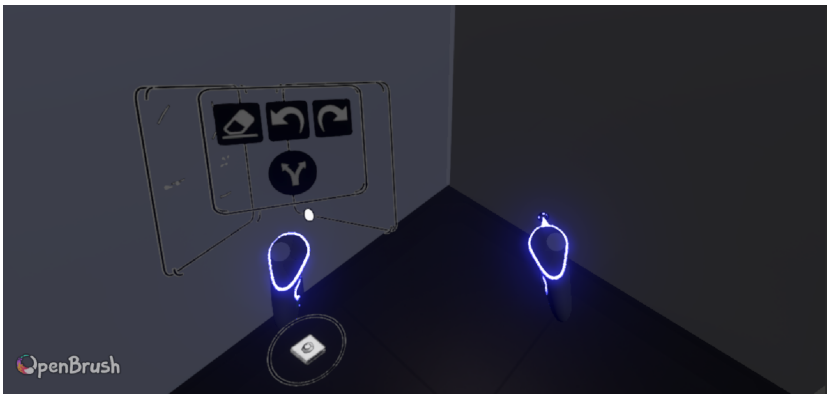


Figure 4.3: Discrete environment walls were added to create a fixed testing area.

As the user tests were conducted at locations chosen by participants, these walls helped us minimize any potential discrepancies between tests and provide each participant with the same level of mobility.

4.2 Second Iteration

In the second iteration of our system, we focused on addressing the feedback received from the first user test, as well as implementing essential new features for the second user test. One of the most significant additions was the implementation of the branching system, which was necessary to manage the asynchronous collaborative artworks and enable users to interact with the version history of each project.

4.2.1 Second Iteration: Incorporating User Feedback

During the first user test, we received feedback from the users that they missed having a dropper tool to easily reuse colors and materials that were previously used but not stored. In response to this feedback, we incorporated an existing Open Brush dropper tool into the Color Wheel menu. We also increased the size of the *Save Color* buttons to make it easier for users to save their selected color. These updates

Figure 4.4: Changes made to the Color Wheel menu. (Left) Original UI. (Right) Dropper added and *Save Color* buttons increased in size for the second user test.

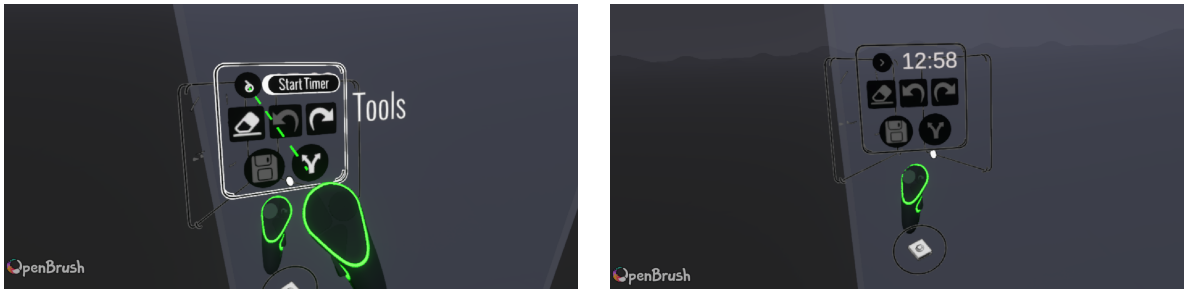


Figure 4.5: User test timer implemented in the Tools UI. (Left) Starting the timer. (Right) Timer in countdown.

were designed to improve the user experience and address the concerns that were raised during the first user test. The changes are visible in Figure 4.4 which provides an example of how the new tool and button changes were incorporated into the Color Wheel menu.

4.2.2 Second Iteration: User Test Timer

In order to provide a standardized testing experience with minimal interference from the user test facilitator, we introduced a 15-minute timer in the interface for the second user test. As soon as the timer button is pressed, the timer starts counting and data collection begins simultaneously. (Figure 4.5) When the timer starts, it plays a sound, and the same sound plays again when 30 seconds remain, reminding users to save their artwork. Finally, the sound plays once more when the timer reaches zero, signaling the end of the user test and prompting users to stop painting.

4.2.3 Second Iteration: User Identification

To enable better data collection and distinguish user interactions within the same HMD during asynchronous collaboration in the second user test, we implemented a user identification button in the system. (Figure 4.6) This feature was limited to pairs of users for the user tests and allowed us to differentiate the actions of each user when interacting with the project.

Figure 4.6: User identification button on the admin menu enables participants to change between user 1 and user 2 during the user test sessions.

4.2.4 Second Iteration: Data Collection

To facilitate data collection for analysis during the painting sessions of the second user test, we implemented a C# script called **TestPrinter**. This script creates two CSV [50] files, namely *controllerDetails* and *headeyePos*, which record the necessary information. The *controllerDetails* file includes logs of the details about the two controllers every 100ms or when the right trigger is activated (when painting or an action occurs), while the *headeyePos* file records the HMD details every 1s. To ensure easy identification of files associated with each user test, we adopted a naming convention that concatenates "controllerDetails" or "headeyePos", the current date and time, and the user selected in the *User Identification* button. For example, two files created in the same session may have the following names:

```
controllerDetails_20230510_152034_User1.csv
headeyePos_20230510_152034_User1.csv
```

This way, we can easily identify the files associated with each user test and analyze the data accordingly.

The *controllerDetails* file captures several variables at each moment, including:

- Time: A string with the time elapsed since the start of the timer;
- Side: A string identifying whether the log is about the left or right controller;
- ControllerPosition: A Vector3 of the current position of the controller;
- ControllerRotation: A Quaternion of the current rotation of the controller;
- TriggerButton: A boolean indicating whether the controller's trigger is being pressed;
- Type: A string of what the user is doing with the controller. It can be an Action (features with instant use like an undo or redo), a Tool (features with prolonged use, like the eraser), or a Stroke (painting);
- StrokeNum: An integer indicating the stroke number, if variable Type is a Stroke;
- Name: If Type is an Action or a Tool, this variable is a string with its identifying name;

- BrushType: A string indicating the name of the brush being used, if Type is a Stroke;
- BrushColor: A Vector4 containing the color code of the painting stroke, if Type is a Stroke.

The variables captured in the *headeyePos* file at each moment are:

- Time: A string with the time elapsed since the start of the timer;
- HMDPosition: A Vector3 of the current position of the HMD;
- HMDRotation: A Quaternion of the current rotation of the HMD.

4.2.5 Second Iteration: Branching System

Implementing the branching system was crucial to our application, giving users the ability to interact with the version history of each art project and manage asynchronous collaborative instances of the artworks. In this subsection, we will discuss the details of how the branching UI works, including how users can view, save, and load different instances, and how the branching system provides a powerful tool for collaborating and managing complex art projects.

4.2.5.A Branching Visualization

In order to provide users with an overview of the version control tree, the branching visualization was implemented. By clicking on the *Branching* button in the main menu, users can access a visual representation of the tree. The instances of the artworks are represented by blocks, while connecting lines show the sequence between them. Included in the visualization are the name and creation date of each instance. The branching visualization appears in front of the user, on one of the four walls, and can span multiple walls if necessary. Figure 4.7 shows an example of the branching visualization and how to access it. This feature offers users an easy way to track changes and understand the structure of the art project.

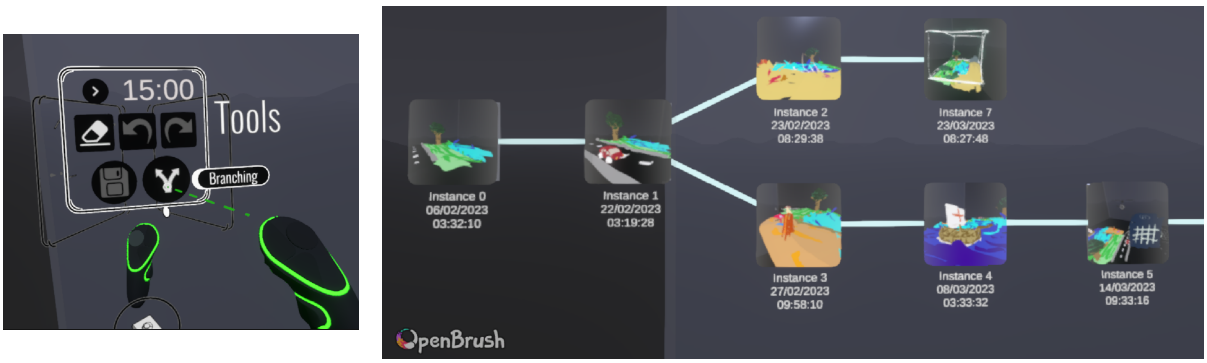


Figure 4.7: (Left) To access the visualization, press the *Branching* button on the Tools menu. (Right) Example of the version control tree of an art project.

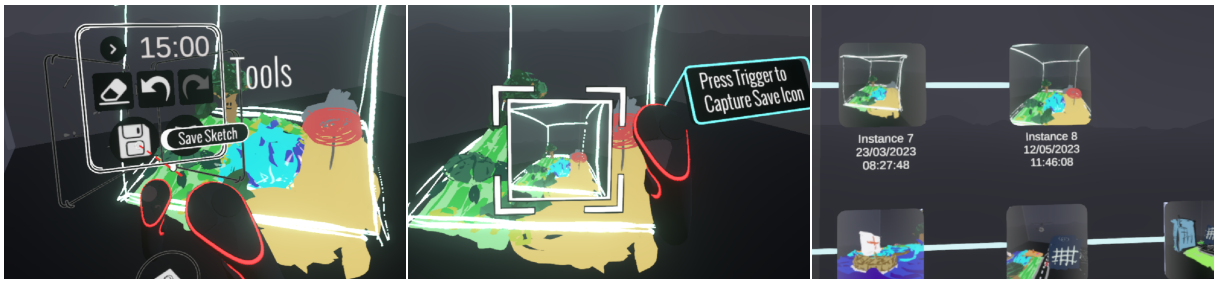


Figure 4.8: Steps to saving instances. (Left) To save an instance, press the *Save Sketch* button on the Tools menu. (Middle) Then, take a photo of the artwork for the instance's thumbnail. (Right) New instance is added to the branching visualization.

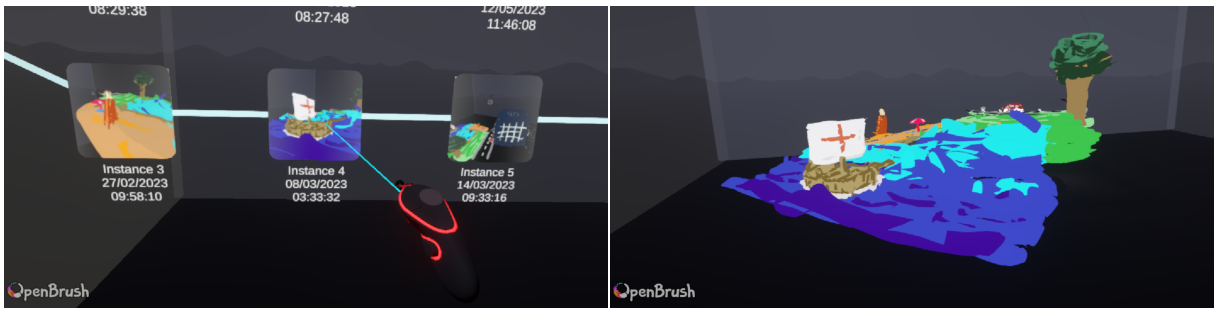


Figure 4.9: Steps to load instances. (Left) After opening the branching visualization, point to the instance to load. (Right) After 5 seconds, the instance is loaded and the user can experiment on the existing artwork.

4.2.5.B Saving Instances

When users want to save an artwork that they painted, they can do so by clicking on the *Save Sketch* button. Upon doing so, the user is prompted to take a photo of the artwork, which is then stored along with the new instance. These instances are represented by their thumbnail images in the version control tree, as seen in the previous subsection, providing a visual history of the project. Figure 4.8 illustrates the process of saving instances in our system.

4.2.5.C Loading Instances

To access previously saved instances, users can use the version control tree by clicking on the *Branching* button in the main menu. From there, they can point to the specific instance they want to load and hold the controller in place to confirm their selection. After holding for 5 seconds, the selected instance will be loaded and displayed in the user's view. This feature allows users to access and view their previously created artwork easily, as well as experimenting on an existing artwork. Figure 4.9 illustrates how users can load previously saved instances from the branching tree visualization.

5

User Evaluation

Contents

In order to address the research questions outlined in Section 1.1 and test the hypothesis presented in Section 1.2, two sets of user studies were conducted with distinct methodologies and objectives. The first user test was essential to finish the development of the system being used in the following user test. Throughout both procedures, information was collected about the users' interactions with the system and their personal opinions about the tasks and the studies.

To collect the most informative feedback, the participants recruited for both studies needed to possess a sufficient level of artistic ability. Therefore, eligibility criteria included either a formal background in the arts, such as holding a degree or being enrolled in an arts program, or amateur experience demonstrated by a portfolio of artworks.

All final artworks created by the users are presented in Appendix A.

5.1 Asynchronous Environment and Branching Interface Preference User Evaluation

The purpose of the first user test was to reach conclusions regarding RQ1 ("Does the immersion and engagement of Virtual Reality provide an adequate environment for asynchronous collaborative art creation?") and its related hypotheses, H1.1 ("While creating art in Virtual Reality, the levels of attention and emotional connection achieved are higher than in real-life art creation.") and H1.2 ("In Virtual Reality, the recognition of asynchronous collaboration is easier for participants, as compared to the real-life scenario.").

With these objectives, participants with artistic backgrounds compared RL and VR asynchronous art creation by collaborating from a starting baseline. They then completed a questionnaire evaluating whether the unique features of VR provided a suitable environment for asynchronous collaborative art creation. Afterwards, the participants were presented with design options for the branching interface required for the continuous study and completion of the system's implementation. They provided feedback on these designs and selected their preferred options.

5.1.1 Participants

For this user test, we recruited eight users from Instituto Superior Técnico (IST) and Faculdade de Belas-Artes da Universidade de Lisboa (FBAUL) university campuses who were previously identified as meeting the artistic requirements for the study. The participants, consisting of six women and two men, were between 19 and 51 years of age ($Median$ = 22.50, $SDev$ = 10.39). Regarding artistic experience, 25% of the participants held an academic degree in fine arts, 25% had work experience in the field, another 25% had both an academic degree and work experience, and lastly, 25% considered themselves

Figure 5.1: RL asynchronous collaborative artwork created by user 6, showcasing the materials provided to the users.

Figure 5.2: User performing the user test by creating art in the VR environment using an Oculus Quest system and a cable connection to a computer.

amateur artists or pursued it as a hobby. Most (75%) of the participants had no prior experience with VR, with only two of them having used it before, and that too, on less than four occasions.

5.1.2 Apparatus

The study made use of different materials for the RL drawing and VR drawing tasks. For the RL drawing task, participants were equipped with traditional drawing tools, including a standard pencil, a set of colored pencils, a rubber, and a black pen. (Figure 5.1) For the VR drawing task, participants used an Oculus Quest system, comprising a HMD and hand controllers. The HMD provided the visual display while the controllers facilitated the interaction and drawing in the virtual environment. To ensure real-time transmission of the Unity-based application to the VR system, a cable connection was utilized, as seen in Figure 5.2. It is worth noting that the VR application used in this user test was still in its early stages, featuring a simplified interface with less drawing space compared to the original version of Open Brush that was used. Furthermore, the absence of asynchronous features in this iteration was intentional, as this user test also aimed to collect user feedback regarding the preferences for the branching and instances interface.

The design options for the branching interface were presented using a PowerPoint presentation, with each option displayed on separate slides. Towards the end of the presentation, a slide showcasing all the designs together was shown, allowing for easy comparison and evaluation.

5.1.3 Procedure

For this user test, eight users were invited to a 30-minute session consisting of two parts. The procedure is described as follows:

Asynchronous Environment Study:

Figure 5.3: RL baseline drawing used as a starting artwork during the first user test.

Figure 5.4: VR 3D baseline painting used as a starting artwork during the first user test.

1. User was given drawing materials and an incomplete RL drawing of a specific scene (Figure 5.3), their task was to complete it within a maximum of 15 minutes. However, they were free to stop earlier if they felt satisfied with their work.

2. The user received an explanation of the VR application and the HMD usage, and was given time to experiment with it. They were then provided with an incomplete VR drawing of a specific scene (Figure 5.4), different from the RL baseline of Figure 5.3, and were tasked with completing it within a maximum of 15 minutes. As with the previous task, they were free to stop earlier if they desired to do so.

3. User was asked to answer Questionnaire 1 (Appendix B), evaluating if the unique features of VR provided an adequate environment for asynchronous collaborative art creation.

Branching Interface Preference Evaluation:

1. In the second part of the study, the user was introduced to the purpose of the planned branching feature. The proposed interfaces designs were shown sequentially in a PowerPoint presentation.

2. The user responded to Questionnaire 2 (Appendix C) where they indicated their preferences and could suggest changes or additional ideas.

5.1.4 Study Design

The study was designed as a within-subjects study, in which all participants interacted with both RL and VR environments for asynchronous collaborative art creation. All participants had a fixed interaction order, starting with RL and then VR. The purpose of this order was to compare the asynchronous collaborative experience of the VR system with the medium that users were the most familiar with, RL art creation.

It is important to highlight that the selection of participants was limited to those with an artistic background. This restriction was chosen to facilitate a meaningful comparison between the RL and VR environments for collaborative art creation. However, it may have limited the generalizability of the study results.

During the study, a cable connection was necessary to connect the HMD to a computer, as there were technological limitations. However, participants expressed that this cable hindered their movement during the study, which is an important consideration for future improvements in the apparatus.

5.1.4.A Measures

In order to assess the **immersion** and **engagement** of the VR environment for asynchronous art collaboration, we collected a variety of measures during the user tests. These measures were aimed at capturing the participants' perception of asynchronous collaboration in VR compared to RL art creation, as well as their preferences for the design of the branching interface.

This user test included administering two questionnaires to the participants. The first questionnaire, presented in Appendix B, sought to compare the participants' experiences in the VR and RL environments, asking them to rate their experience in various aspects. This allowed us to collect their **perception of asynchronous collaboration**, **attention**, **emotional connection** and determine the adequacy of VR as an environment for this type of art creation. The second questionnaire, presented in Appendix C, focused on collecting feedback specifically related to the design of the branching interface to be developed for the VR application. By soliciting participants' preferences, we gathered responses related to the user experience of different interface designs.

During the VR session, we collected several metrics to understand how the artists interact with the application. These included tracking the features used, the number of brushes, colors, and paint strokes used by each user. The findings from these metrics guided the iterative process of the system for the following iteration, ensuring that it aligns with the artists' needs and preferences in order to improve their experience with the application.

5.1.5 Results

5.1.5.A RL and VR Environments

To thoroughly evaluate the usability, immersion, and engagement of the VR environment compared to the real-life environment, we designed Questionnaire 1, taking inspiration from the established System Usability Scale (SUS) [51], which we identified as being most aligned with our evaluation objectives. The usability questionnaire comprised Likert scale questions that effectively measured various dimensions of usability, including ease of use, learnability, and overall satisfaction with the environments.

Table 5.1: Comparison of users' responses to Questionnaire 1 with their perceptions of RL and VR art creation. Median, standard deviation and T-test values are presented, where the p-value is the test statistic and α the significance level for rejecting H_0 or failing to reject H_0.

	RL		VR		T-test	
Closed question	Median	SD	Median	SD	p-value	α
1. By completing the artwork, I was collaborating with other artists	3.5	1.58	5	0.35	**0.01**	0.02
2. I felt close to the original artist of the artwork	2.5	1.06	5	0.74	**1.74E-03**	0.01
3. I understood the objectives given to me	5	0.74	5	0.71	0.18	H_0
4. I found the objectives easy to complete	4.5	0.99	4	0.99	0.50	H_0
5. I was in control of the changes made to the artwork	5	0.71	5	0.74	0.38	H_0
6. My interactions with the artwork were natural	4	0.52	5	1.06	0.26	H_0
7. The surrounding environment was ideal for art creation	4	0.46	5	0.71	**0.05**	0.10
8. I was immersed in completing the artwork	5	0.52	5	0.35	0.37	H_0
9. I felt engaged to complete the artwork	5	0.52	5	0.71	0.30	H_0
10. I had fun while working on the artwork	5	0.46	5	0.35	0.30	H_0
11. I was comfortable during this collaborative work	5	0.00	5	0.35	0.18	H_0
12. The finished artwork is original	4	0.99	5	0.76	**0.04**	0.05
13. The finished artwork is elegant	3.5	0.99	4	1.07	0.30	H_0
14. The finished artwork was better with collaboration	5	0.52	5	1.06	0.16	H_0
15. I imagined different possibilities that I could try in this artwork	5	0.92	5	0.46	0.38	H_0

Note: Scoring from 1 (completely disagree) to 5 (completely agree)

The responses provided by the users are presented in Table 5.1 along with accompanying statistical analysis and the results of a T-test [52] statistical test. A T-test is used to determine if there is a significant difference between the means of two groups. For this data, we used a one-tailed paired T-test for each question in the questionnaire. A paired T-test is used when comparing two different measures to the same subjects, which in this case are the two environments being evaluated. A one-tailed test is used when testing the relationship of the two measures in one direction, in this case, to verify if the VR environment has certain advantages over RL, as per our research questions. The null hypothesis (H_0) for the T-test is that there is no significant difference between the two environments for the question being tested. Rejecting the null hypothesis assumes there is a significant difference between the two environments in favor of the VR environment. In our study, we have chosen significance levels (α) of 0.1, 0.05, 0.02, and 0.01, which represent the probability of rejecting the null hypothesis when it is true. A smaller significance level indicates a more strict test, requiring stronger evidence to reject the null hypothesis.

Analysis using the T-test to our Questionnaire 1 results revealed that H_0 was rejected for questions 1, 2, 7 and 12, showing that the VR environment had significantly better results compared to the RL environment. However, for the remaining questions, H_0 was not rejected, suggesting no significant difference between the two environments in those aspects.

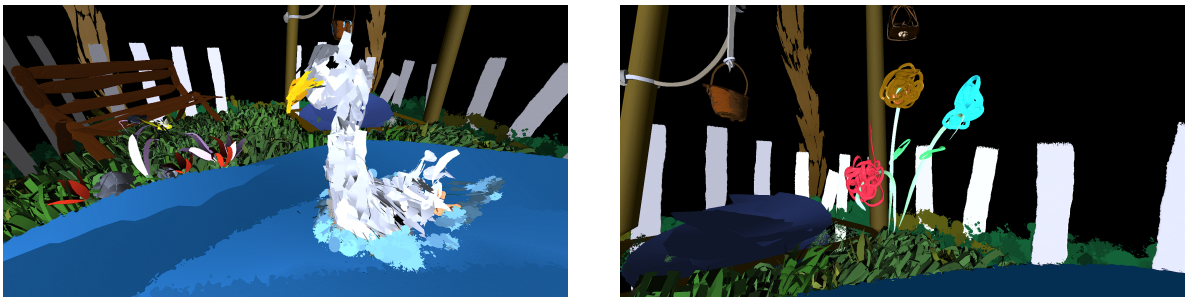


Figure 5.5: Variety of color usage in VR sessions. Example from user 2 on the left and from user 8 on the right.

During the VR session, we collected several metrics to better understand the artists' interactions with the application. The results were:

- All users used the eraser or undo feature, or both. 87.5% of users scaled, rotated or moved the drawing using the embedded feature to adjust their view. 71.4% of users used the feature for resizing brushes.
- The artists experimented with several brushes, but eventually, most (62.5%) settled on using 3 to 4 brushes as they were their favorites or matched the baseline art style of the asynchronous collaboration.
- Users generally (62.5%) used 14 or more colors in their session. (Figure 5.5)
- Some users reported difficulty in matching the colors and brushes from their previous strokes to the starting artwork.
- The number of painting strokes ranged from 31 to 118 ($Median$: 105, $SDev$: 31.13).
- Users tended to focus on the same zones, which were mainly where the baseline's artist left contributions. However, users also expressed differing ideas for the spaces, as exemplified in Figure 5.6.

Overall, these metrics provided valuable insights into the users' engagement with the VR application, as we had simplified the original interface from the Open Brush version being used. With these insights, we were able to further improve the system for the subsequent iteration. One of the changes we made was implementing a dropper feature to address the reported issue with matching the colors and brushes.

5.1.5.B Branching Interface Preferences

During Questionnaire 2, participants provided feedback on the branching interface design options presented during the user test. The closed questions were repeated for each design, and optional open-ended questions were included to gather feedback on improvements, unexpected features, and the applicability of the branching design options for the user's artistic expression. Additionally, participants

Figure 5.6: Collaborative contributions to the same spaces with unique artistic perspectives. Top row displays user 2 and user 7's additions to the well bucket, while the bottom row showcases user 1 and user 4's contributions to the lake.

were asked to provide their opinions on which options corresponded more closely to the problem presented to them.

To facilitate discussion and analysis, the interface designs were named according to a where-what-how structure that distinguishes the characteristics of the designs. The 'where' indicates the location where the branching interface can be accessed, either in the left-hand *menu* of Open Brush or through a single *button*. The 'what' describes the type of information displayed, which can be either text-based *info* or an *image* for visual representation. Finally, the 'how' denotes the method of navigation through multiple pages of instances, either through *arrows* for multiple pages or *scroll* within a single page.

We opted to use the User Experience Questionnaire Short Version (UEQ-S), [53] a shorter version of the User Experience Questionnaire, as the basis for our questionnaire. Since participants were required to complete it for each design presented, the short version was more suitable due to its brevity. The UEQ-S is a questionnaire for assessing users' subjective experiences based on their interaction with an interface or product. In this user test, users did not interact with the designs, so we adapted the questionnaire as to provide first impressions on the interfaces based only on the visual appearance of the designs.

Figures 5.7 shows the interface designs presented to the users and Figure 5.8 the corresponding questionnaire results. The overall scores obtained from the responses to Questionnaire 2 are presented in Figure 5.9, where the designs Button-Image-Arrows, Button-Image-Scroll and Menu-Image-Scroll re-

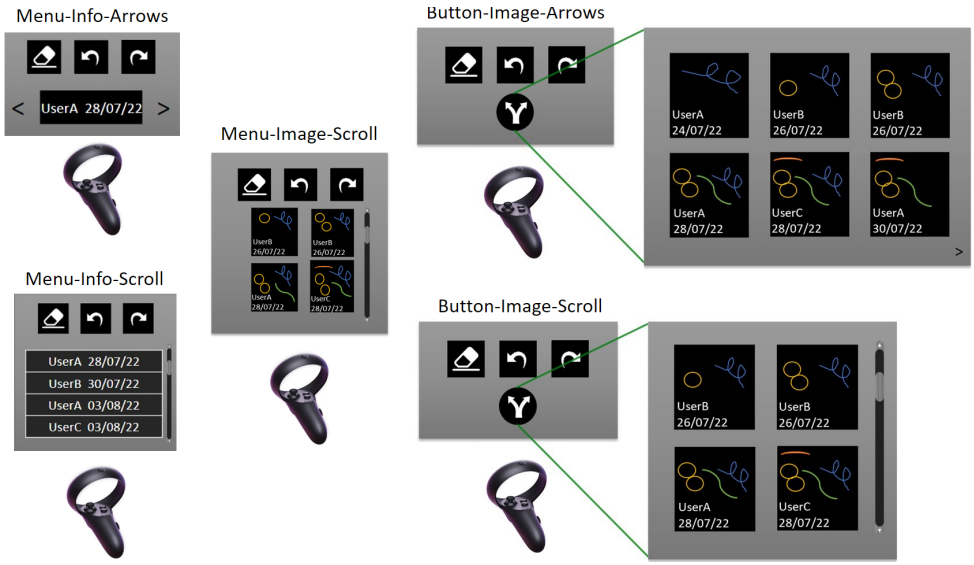


Figure 5.7: Interface designs presented to the users.

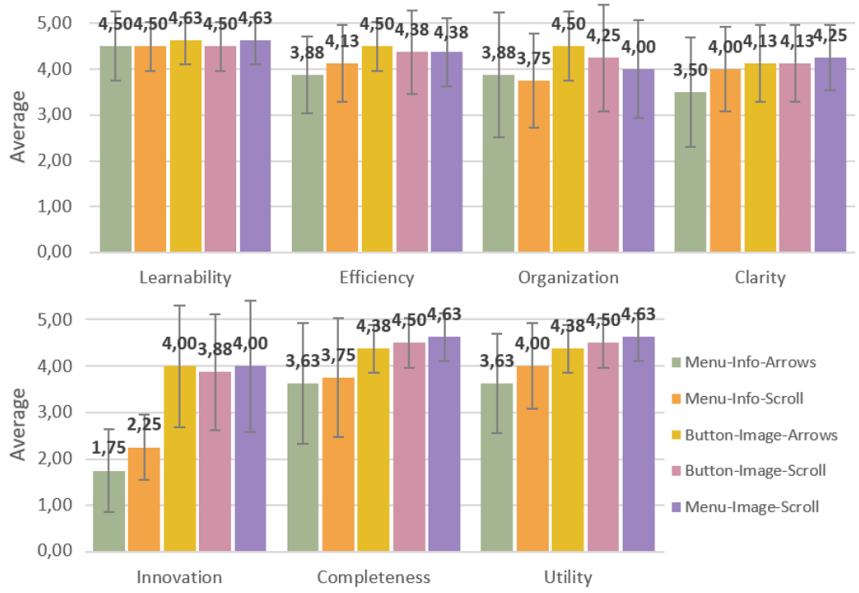


Figure 5.8: Bar chart presenting the results of Questionnaire 2 for the interface designs. The chart displays the average scores per question, measured on a scale of 1 to 5, with 5 being the highest score. The chart also includes the standard deviation error bars for each question.

ceived the highest scores. It is important to note that all questions were given equal weight in determining the overall preference score. Additionally, participants were asked to indicate their overall preferred interface design option, and designs Button-Image-Arrows and Button-Image-Scroll tied with the most votes, as shown in Figure 5.10.

After reviewing the open-ended responses regarding possible improvements and necessary features, users expressed a preference for an interface design that would include the visualization of instances and

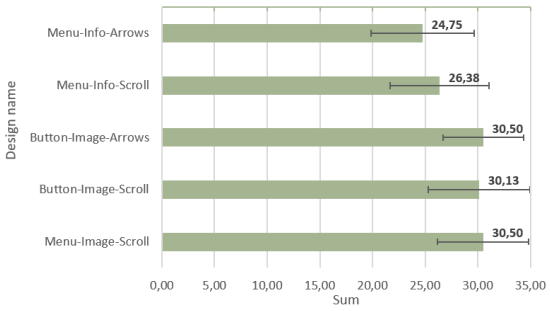


Figure 5.9: Bar chart displaying the total sum obtained from the responses to Questionnaire 2, measured on a scale of 1 to 5 for each question, with 5 being the highest score. The chart also includes the standard deviation error bars for each design.

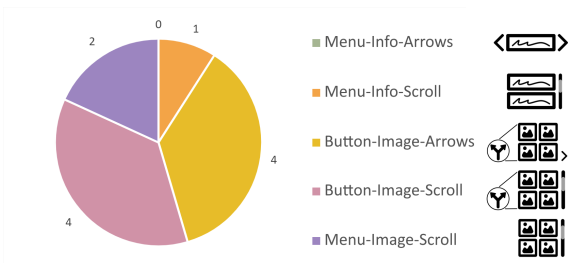


Figure 5.10: Pie chart showing users' overall preference for branching interface design options, with each option labeled by a representation of its distinguishing features. These results represent the answers to a multiple-choice question.

a timeline effect. To meet this preference, we implemented a design that closely resembled the Button-Image-Arrows and Button-Image-Scroll options, while incorporating the desired visualization features.

5.2 Continuous Asynchronous Collaboration User Evaluation

Building on the insights gained from the previous user test, we incorporated the findings into the development process of the system. The second user test involved the full implementation of the system, including the branching capabilities outlined in Section 4.2.5.

The objectives of the following user test were mainly to explore the hypotheses H2.1 ("Artists prefer to paint in specific sections of their artwork, creating their own working areas."), H2.2 ("The number of new branches created will increase over the evaluation sessions."), and H2.3 ("The mean number of painting strokes is greater in a newly created branch than in the asynchronous collaborative branch."). These objectives aimed to address the research question RQ2 ("Does asynchronous collaboration in Virtual Reality still allow artists to feel ownership over the creative process? To what extent do artists explore different ideas for an art piece?").

For this purpose, users utilized the interface to engage in an asynchronous collaborative artwork creation process over multiple sessions. In this study, participants were paired up, but worked on the art project independently, with no direct communication or knowledge of their partner's identity. At the end of each session, they completed a questionnaire regarding their satisfaction with the session. After the completion of all the individual sessions, participants met for the first time and engaged in a structured pair-interview to discuss their collaborative project.

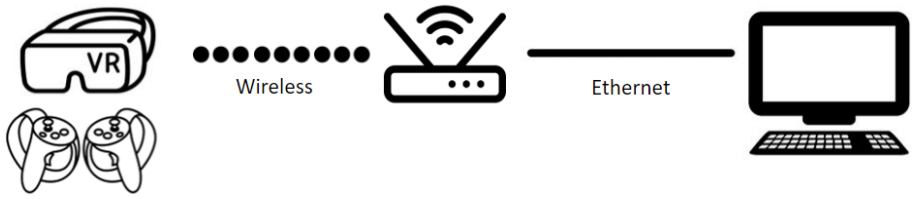


Figure 5.11: Diagram of the test apparatus used for the second user test, featuring improvements based on feedback from the pilot of this user study. In contrast to the cable used in the first user test, a LAN connection was implemented.

5.2.1 Participants

For this user test, we recruited eight users and organized them into four pairs. These users were from IST and FBAUL university campuses and were recognized as meeting the artistic requirements for the study. The participants, consisting of five women and three men, were between 18 and 62 years of age ($Median$ = 21, $SDev$ = 17.63). Regarding artistic experience, 12.5% of the participants were currently enrolled in an academic degree in fine arts, 25% had work experience in the field, 12.5% had both an academic degree and work experience and 50% considered themselves amateur artists or pursued it as a hobby. Like the previous study, most participants had little to no prior experience with VR, with five reporting little experience and three indicating no experience at all.

5.2.2 Apparatus

In this study, users engaged in asynchronous collaborative art creation using an Oculus Quest 2 system, comprising a HMD and hand controllers. As in the previous study, the HMD provided the visual display, while the controllers facilitated the interaction and drawing in the virtual environment. Based on the feedback received during the pilot test for this study, we established a Local Area Network (LAN) connection between the Unity-based application and the VR system, rather than using a cable connection. We connected the computer running the application to a router via an Ethernet cable, which then wirelessly connected to the HMD, as illustrated in Figure 5.11. This approach allowed users to move freely, avoid internet speed limitations and ensure real-time transmission to the application.

5.2.3 Procedure

For this user test, we selected eight users who were paired up but were unaware of each other's identity. The test was divided into three parts, starting with an initial 25-minute introduction session, followed by four 20-minute painting sessions, and finally a pair-interview that lasted around an hour. The procedure shown in Figure 5.12 is described as follows:

Initial session:

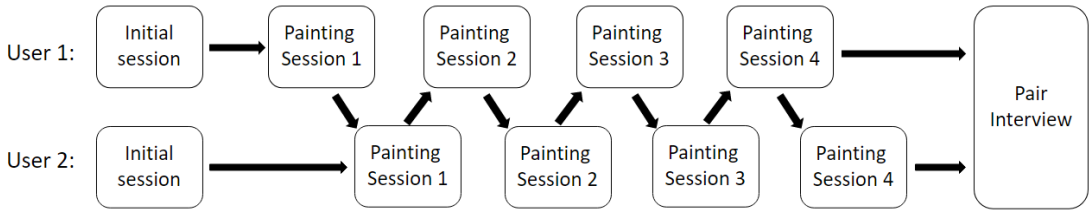


Figure 5.12: Overview of the user testing procedure.

1. Each user was invited to an initial session where we explained the purpose of the application and defined their role in the study.

2. User watched an introductory video that demonstrated the tools and functionalities of the VR application. (Figure 5.13)

3. Users then had 10 minutes to trial the system and complete a series of tasks intended to reinforce how the branching feature works. These tasks were completed sequentially, with the same starting point in the VR environment for every participant. Participants were encouraged to ask questions if they had any during this process.

   The tasks were as follows:

   - Task 1: Draw a simple table.
   - Task 2: Save the current progress (creating the first instance).
   - Task 3: Draw a book on the table.
   - Task 4: Save the current progress (creating the second instance).
   - Task 5: Use the Branching menu to open the first saving point and draw a vase on the table.
   - Task 6: Save the current progress (creating a branch).

   After completing these tasks, users should have a version tree that matches the structure illustrated in the Figure 5.14.

4. Finally, users were asked to complete a brief demographic questionnaire that included a consent form for the study, as well as questions designed to measure their tendency for immersion. This questionnaire (Questionnaire 3) can be found in Appendix D.

Asynchronous painting session (4 sessions):

1. Participants engaged in a series of limited asynchronous VR painting sessions. Each pair of users completed a total of eight sessions, alternating between working on the project individually with each user completing their own set of four sessions. During each session, participants were given a maximum of 15 minutes to work on the project in the VR application, with the option to end

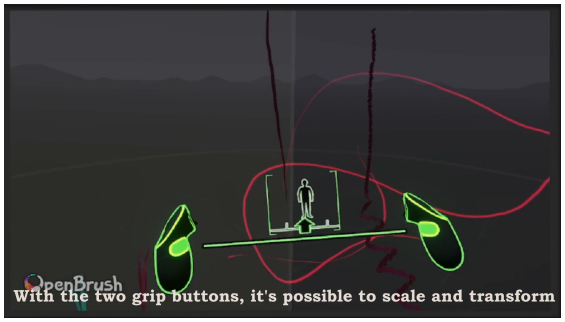


Figure 5.13: Still frame of the introductory video[1], explaining the transformation feature.

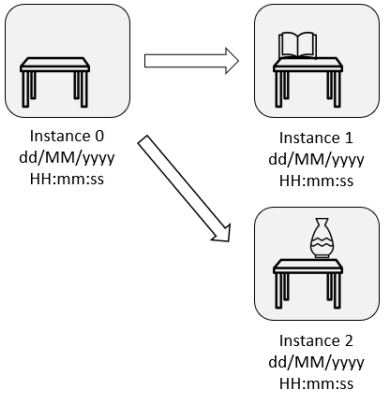


Figure 5.14: Expected branching interface after successfully completing the tasks of the initial session of the second user test.

the session earlier if desired. It is worth noting that, besides the time limit, participants were also required to save their work at least once. The test moderator did not intervene in the sessions, leaving the participants with the time limit present in their UI.

2. In order to acquire insight into the user's level of immersion and engagement during the session, participants were asked to answer a memory question. Users were presented with a randomly selected question from a set, with no repetitions. The set of memory questions was the following:

   - Question 1: What are some objects you sketched on the artwork today?
   - Question 2: List the current most relevant elements of the artwork.
   - Question 3: How many colors did you use in the artwork today?
   - Question 4: What objects are in the 'X' section of the artwork?

   It is important to note that Question 4 was never presented in the first painting session to ensure that participants had first identified 'X' as a relevant element in their artwork in response to Question 2. This helped to ensure that the responses to Question 4 were accurate and reflective of participants' engagement with the session.

3. After each painting session, the user was asked to complete Questionnaire 4 (Appendix E). This questionnaire was designed to record the user's overall appreciation of the session, as well as their thoughts on their collaborator's contributions and their reasoning behind any created branches and multiple saved instances.

Final pair-interview:

[1] https://youtu.be/Za8fHLUUoH8

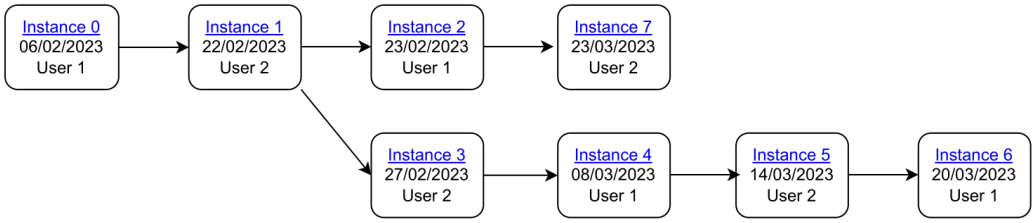


Figure 5.15: Example of tree visualization delivered to the users before the interviews. It shows the multiple versions of the project created, with each instance including a link to an interactive 3D image of the artwork, the date of creation, and the user who created it.

Before the interview, the users were provided with a visualization of the multiple versions of the project organized in a tree structure, as shown in Figure 5.15. The project instances included links to interactive 3D images that were created using the open-source web page Icosa Gallery [54] from the original .glb files (binary file format representation of glTF [55]).

During the scheduled pair-interview, which was the first time the users met their asynchronous collaborator, the following questions were asked in no particular order:

- In terms of quality, how do you feel about your individual work and your collaborator's work?
- Why did you decide to (not) create a new branch? Was the creation of branches relevant to your creative process?
- Do you consider the instances of the artwork as individual? Or do you feel you share ownership of it? What about the branches developed?
- Why did you (not) destroy brush strokes your collaborator made?
- To what extent did you feel that you lost track of time during the art creation?
- To what extent did you feel aware of being in the real world while painting?
- What challenges did you feel with asynchronous collaboration?
- Because of the asynchronous nature of this artwork's creation, did you feel that communication with your collaborator was one of the major concerns?
- What would you do differently if this artwork was done synchronously?
- Would you have preferred to meet previously to the study to discuss objectives and ideas for the artwork?
- What features do you think could be added to the application to make it better?
- Which aspects and tools did you find most useful? Were there any features that you found unnecessary or not essential to achieving your goals?

5.2.4 Study Design

The study was designed so that participants engaged with the same VR environment and UI throughout four painting sessions, fostering asynchronous collaborative art creation. Their interaction with the system was then compared against their prior experiences in RL collaboration. All users actively took part in the three parts of the user test, the introduction phase, the painting sessions, and the pair-interview.

To improve the procedure and study design, we conducted two pilot studies and made changes based on the collected feedback. One of the most significant changes was pairing up participants without introducing them to each other at the beginning of the test, as pilot users indicated that meeting at the start was unnecessary, less interesting, and could potentially lead to unintended contact. Additionally, meeting at the beginning could be intimidating for users who were paired with someone who held a position of authority, had more experience, or was older than them. The pilot also helped us improve the user experience by creating an introductory video and setting up a router with LAN connection to avoid the inconvenience brought by the cable usage in the apparatus.

We chose to restrict participants to those with an artistic background, which may have limited the generalizability of the study results. Scheduling was carefully done with the 8 participants, with pairs formed according to similar availability, as we only had one HMD available. The order of the pairs and who started the artwork first, depended on the availability to schedule the first session, which may have affected the results.

Before each painting session, users were reminded that they could save their project as many times as they desired and start drawing from whatever saved instance they preferred. Users started every session in the same position and direction in the room. They were permitted to create multiple branches and instances within the same session to experiment with different approaches to their artwork. Additionally, participants were required to save their work at least once.

5.2.4.A Measures

The measures collected during the user test in asynchronous collaboration were designed to understand the impact of VR on artists' sense of **ownership** over the creative process and their **willingness to explore** different ideas for an art piece. To achieve this goal, we used various methods of data collection throughout the study.

First, two questionnaires were administered to the participants. The first questionnaire was a brief demographic questionnaire that also included a consent form for the study, as well as questions designed to measure the users' tendency for immersion. This questionnaire is presented in Appendix D. The second questionnaire, presented in Appendix E, was prompted at the end of every painting session and was designed to record the user's overall appreciation of the session. The questionnaire recorded the participant's **thoughts** on their **collaborator's contributions**, as well as their **reasoning** behind any **created branches** and **multiple saved instances**. Also in this questionnaire, participants were asked to answer a memory question to understand their level of **immersion and attention** during each session.

During the VR painting sessions, several metrics were collected to measure the artists' engagement with the application and their artworks. These metrics included the recording of the HMD and controllers'

positions to measure distances and patterns (H2.1), tracking the number of branches created by the artists (H2.2), and documenting the count of brush strokes made in leaf instances and newly created branches (H2.3).

As a precaution against problems that could arise in the data collection, a video of the users' perspective during the session was also recorded, with their consent. These metrics were used to understand the user's engagement with the application and to guide the iterative process of the system for the following iteration.

In the final interviews, several main topics were discussed with participants, including:

- Satisfaction with their own and their collaborator's work;
- Reasons and contributions of branching;
- Sense of ownership over the artwork;
- Level of immersion in the virtual environment (time and space);
- Experiences with asynchronous versus synchronous collaboration;
- Communication in asynchronous collaboration;
- Feedback on technical aspects of the system.

Participants were also asked to provide recommendations and identify any issues or drawbacks they encountered while using the system.

5.2.5 Results

5.2.5.A Demographics and Immersion Tendencies

To collect data on user demographics and immersion tendencies, Questionnaire 3 was administered during the initial session of the user test. The questionnaire consisted of three parts: consent for the study, user demographics, and immersion tendencies. The immersion tendencies part of the questionnaire was based on the Immersive Tendencies Questionnaire by B. Witmer and M. Singer. [56] This section of the questionnaire was designed with the expectation that users with higher immersive tendencies would become more involved in virtual environments. The demographic answers are presented in Section 5.2.1.

5.2.5.B Memory Questions

As stated in the procedure of this user test (Section 5.2.3), the participants were asked to answer a set of memory questions after every painting session, which enabled us to gain a deeper insight into their attention and engagement during the sessions. The full results of the immersion tendencies and success

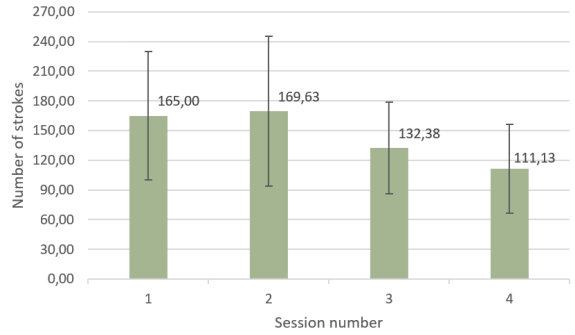


Figure 5.16: Bar chart with the average number of painting strokes performed by users per painting session.

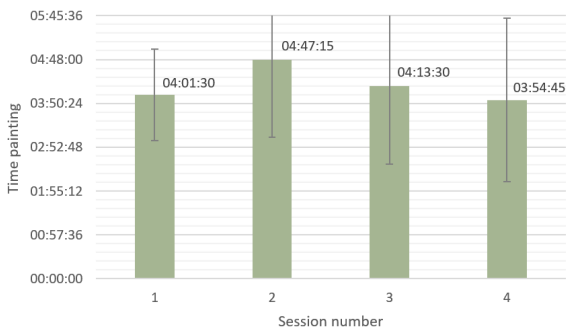


Figure 5.17: Bar chart showing the average time spent painting per painting session by all users.

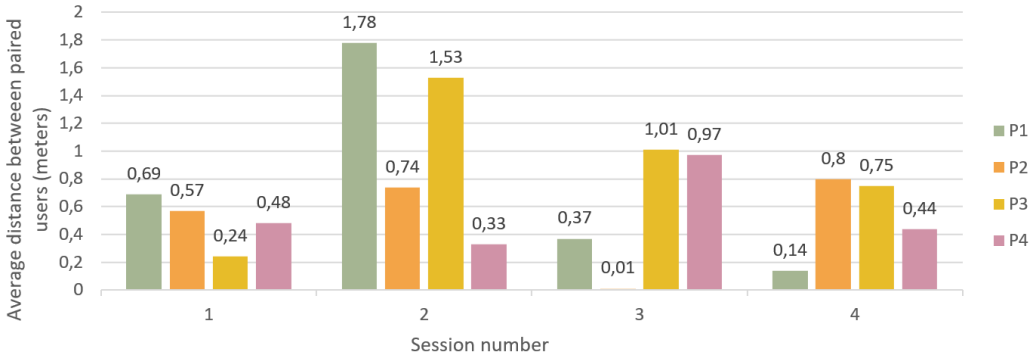


Figure 5.18: Bar chart with the average distance between paired users in each painting session.

rates in memory questions are presented in Table F.1. According to the results, there is a wide range of immersion tendencies that range from 46.67% to 86.67%. Most of the users achieved a perfect success rate in memory questions, where only one user had a success rate lower than 80%. To investigate if there is a correlation between the two variables, we used Spearman rank correlation coefficient [57] and found no significant correlation between immersion tendency and success rate in memory questions. Notably, the lower success rates were not low enough to suggest that the participants were not focused or attentive during the user test.

5.2.5.C Painting Sessions Analysis and User Satisfaction

To measure user satisfaction with the painting sessions and their results, Questionnaire 4 was administered at the end of every session, asking participants to rate their satisfaction with their own work, their collaborator's work, their cognitive load, and regarding negative emotional responses. Additionally, participants were asked about their motivation for creating new branches or saving multiple instances during the session, if applicable.

During the VR painting sessions, users utilized the first session to establish the theme, define the

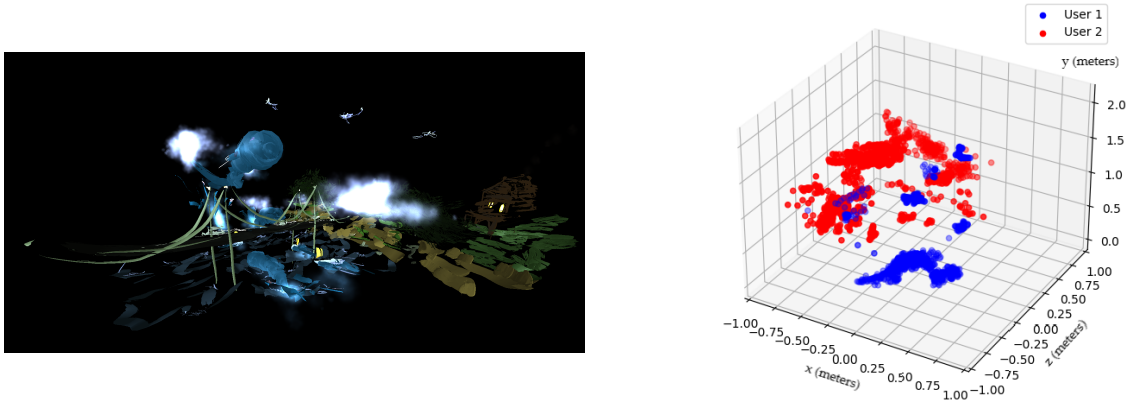


Figure 5.19: Example in which the artists painted away from each other's contributions. (Left) Instance created by user 2 of pair 3 (P3U2) during the second painting session. (Right) 3D Scatter plot of the HMD positions of the third pair's users during the second session.

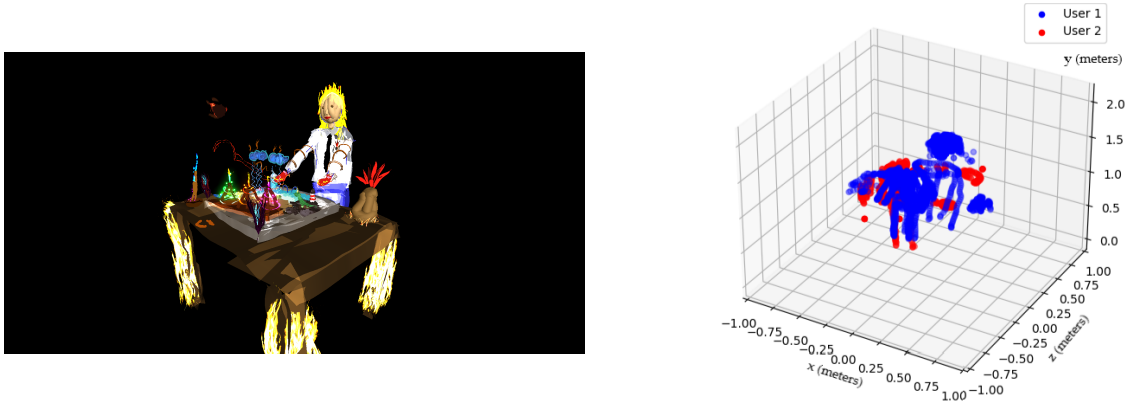


Figure 5.20: Example in which the artists painted close to each other's contributions. (Left) Instance created by P1U1 during the fourth painting session. (Right) 3D Scatter plot of the HMD positions of the first pair's users during the fourth session.

main elements of the artwork, and familiarize themselves with the tools. The majority of strokes were painted during the first and second sessions, as depicted in Figure 5.16. However, the time dedicated to painting was evenly distributed across the sessions, with the peak occurring during the second session, as shown in Figure 5.17.

After the painting sessions, we measured the average distance between paired users per session, as presented in Figure 5.18. Notably, the second session exhibited a significant increase in the average distance between users compared to the other sessions, indicating that users were creating art in more distant zones from each other. The third pair of users consistently showed the greatest average distance, indicating a higher degree of spatial separation while creating art, as demonstrated in Figure 5.19. In contrast, the second pair of users demonstrated the closest proximity, with one session registering a minimal distance of '0.01' between the users. To illustrate the type of close work that some pairs of users engaged in, we provide examples of pair 1's artworks from session 4 in Figure 5.20. In addition

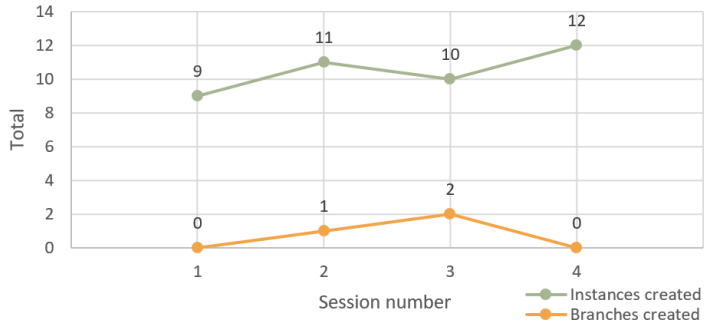


Figure 5.21: Scatter plot with total number of instances and branches created in each session.

Table 5.2: Table showing for each newly created branch, which user created the branch, in what painting session and the number of strokes in that branch. We also present the average strokes in leaf instances (LI) of the artwork performed by the corresponding user.

User identification	Branch creation session	Strokes in branch	LI strokes average
P2U2	2	142	152,67
P1U1	3	76	190,00
P3U1	3	138	158,33

to the average distance analysis per pair, we also collected data on the maximum distance between strokes performed by users per session, as presented in Table F.2.

When analyzing the creation of instances and branches across painting sessions, we observed a slight upward trend, as depicted in Figure 5.21. Users tended to paint fewer strokes within the branches, as evidenced by the data in the Table 5.2. In terms of user satisfaction, our findings indicated that users reported higher satisfaction with their individual work in leaf instances compared to branches, as shown in Table 5.3. Additionally, users generally expressed greater satisfaction with their collaborator's work in leaf instances and, on the other hand, reported lower levels of mental ease and motivation when working on branches, as opposed to leaf instances.

Table 5.3: Table comparing, for each new branch created (identified by user and creation session) the questionnaire responses given by each user relating to satisfaction, mental ease and motivation, with the average of that user's responses given when in a leaf instance (LI).

	In branch			LI averages		
Branch identification	Satisfied with individual work	Satisfied with collaborator's work	Mental ease and motivation	Satisfied with individual work	Satisfied with collaborator's work	Mental ease and motivation
P2U2-2	2,00	1,00	1,00	4,00	3,00	3,83
P1U1-3	3,00	3,00	2,00	4,33	5,00	3,00
P3U1-3	4,00	5,00	2,00	3,33	4,50	1,83

Note: Scoring from 1 (completely disagree) to 5 (completely agree)

5.2.5.D Interview Insights

Following the interviews, we used the automatic transcription service Good Tape [58] to transcribe the recorded conversations. This allowed us to extract the following key insights from the questions asked:

- Collaboration Quality: Users expressed a positive view of the collaboration, particularly appreciating the quality of their collaborators' contributions. Only one user expressed dissatisfaction with their collaborator's contributions;
- Branching: Three users (P1U1, P2U2 and P3U1) created branches for different reasons, but all were satisfied with the existence of this feature. Reasons for branching included:
  - Dissatisfaction with the latest collaborator's contribution: " I was trying to find a theme based on what they (the collaborator) had done. They drew a comet that didn't have much to do with it. But I found it interesting and tried to continue from there. I thought they would do the same. But it didn't happen" (P1U1);
  - Liking the collaborator's idea but not the execution: "I found it (the recent instance) a bit awkward because when I looked at your (the collaborator's) initial idea, I saw that it was an infinite sea and you closed it and it became just a lake" (P2U2);
  - Experimentation that did not yield the expected result: "I didn't like how the submarine looked, but I left it there in case P3U2 wanted to continue from there" (P3U1).
- Non-Branching Users: The remaining five users who did not create branches had various reasons for their decision. Three cited lack of time, with two of them stating that they would have created branches if there were more painting sessions. The other two users preferred to take on a supportive role and contribute solely to their collaborator's ideas;
- Ownership: All users perceived the artwork as a shared ownership, even in instances created by branching;
- Planning: Users rarely planned their contributions in advance and found the unpredictability of their collaborator's ideas to be entertaining and pleasantly surprising. However, one user expressed a desire to set guidelines and themes for the art project with their collaborator;
- Time Awareness: 37.5% of the users were highly conscious of the remaining session time, with their artwork details and ideas changing accordingly. The remaining users reported consistently forgetting about the time constraint;
- Spatial Awareness: Users had limited awareness of the real world while immersed in the VR environment. Three users even reported accidentally hitting the controllers on the HMD due to a lack of spatial awareness;

- Asynchronous Collaboration: Users appreciated the asynchronous collaboration and the absence of communication between collaborators. However, 25% of the users reported some confusion in following their collaborator's theme and generating new ideas;
- Anonymity: Users valued the anonymity provided by the system, feeling less pressured in the results and more comfortable expressing opinions about their collaborator's work, which they believed to be more impartial;
- Technical Features: Users expressed a desire for additional technical features in the system. This included pre-made shapes, color replacement, volume color filler, and a selective eraser that can erase part of a branching stroke instead of the entire stroke. Some of these features are currently limited by Open Brush, and others exist in more recent versions of the application.

Overall, users expressed satisfaction with the results of the asynchronous collaboration art creation, embracing the opportunity to collaborate in a unique and unconventional manner. They demonstrated respect for their collaborator's contributions and actively pursued the creation of an original artwork while incorporating elements they personally enjoyed.

5.3 Discussion of Results

Based on the results of the questionnaire regarding the RL and VR environments for asynchronous art creation, presented in Table 5.1, we can derive some observations regarding RQ1 ("Does the immersion and engagement of Virtual Reality provide an adequate environment for asynchronous collaborative art creation?") and its related hypotheses. Specifically, H1.1 ("While creating art in Virtual Reality, the levels of attention and emotional connection achieved are higher than in real-life art creation.") will be addressed in Section 5.3.1, while H1.2 ("In Virtual Reality, the recognition of asynchronous collaboration is easier for participants, as compared to the real-life scenario.") will be explored in Section 5.3.2. The remarks related to RQ1 will be presented in Section 5.3.3.

To address RQ2 ("How does the use of Virtual Reality for asynchronous collaboration impact artists' sense of ownership over the creative process? To what extent do artists explore different ideas for an art piece?") and its associated hypothesis H2.1 ("Artists prefer to paint in specific sections of their artwork, creating their own working areas."), H2.2 ("The number of new branches created will increase over the evaluation sessions.") and H2.3 ("The mean number of painting strokes is expected to be higher in newly created branches compared to the asynchronous collaborative branch."), we analyzed the Questionnaire 4, the pair-interview and the data collected during the VR painting sessions. The findings shed light on artists' sense of ownership over the creative process and their exploration of different ideas in VR. Specifically, H2.1 will be addressed in Section 5.3.4, while H2.2 and H2.3 will be discussed in Section 5.3.5. The overall analysis and remarks regarding RQ2 will be presented in Section 5.3.6.

5.3.1 Attention and Emotional Connection

The T-test results indicate that participants experienced a stronger emotional connection with the asynchronous collaborator in the VR environment compared to the RL environment. This is evidenced by the significant difference observed in question "2. I felt close to the original artist of the artwork" of Questionnaire 1.

Regarding attention levels, the questions "3. I understood the objectives given to me", "8. I was immersed in completing the artwork" and "9. I felt engaged to complete the artwork" showed no significant difference between the two environments. However, the data distribution reveals consistent high scores in both environments, indicating similar levels of attention across the board. This pattern is also observed during the multiple painting sessions in the VR environment of the second user test, where users were asked memory questions to evaluate their attention, emotional engagement and information retention. It is worth noting that immersion and memory have been shown to be interconnected [59], and the success rates of the questions were overwhelmingly high, with the lowest recorded at 75%. In the pair-interviews of that user test, participants reported that, regardless of being in control of the remaining time, they were highly focused on the art project and actively planning their ideas.

These findings partially support H1.1, showing that the emotional connection achieved during art creation in the VR environment is higher than that achieved in RL art creation. However, the conclusions related to the levels of attention suggest that both environments offer similarly high levels of immersion.

5.3.2 Recognition of Asynchronous Collaboration

The data collected confirmed hypothesis H1.2, which suggested that users would find it easier to recognize asynchronous collaboration in VR compared to a RL environment. This is supported by the significant difference in the users' responses to question "1. By completing the artwork, I was collaborating with other artists".

5.3.3 Adequacy of VR as an Environment for Asynchronous Collaborative Art Creation

Users showed a similar level of understanding of the art creation objectives in both VR and RL, however completing the tasks in the VR environment proved to be more challenging. Despite reporting that their interactions with the artwork felt natural in both environments, participants had to learn a lot about the possibilities of the system in a short period of time, especially since many of them had their first experience with VR in this study.

The T-test also revealed that there is a significant difference in the results of "12. The finished artwork is original" in VR compared to RL, likely due to the novelty of the VR environment. Additionally,

the T-test did not reveal a significant difference in the results of “14. The finished artwork was better with collaboration”. This, together with the high values observed for both environments, indicates that collaborative artworks created in either environment can be satisfying for users.

The questions “10. I had fun while working on the artwork” and “11. I was comfortable during this collaborative work” received similar high scores in both environments. This suggests that users found the art creation process enjoyable and comfortable in both settings. The question “7. The surrounding environment was ideal for art creation” was answered with a significantly higher score in VR than in RL, suggesting that users found VR to be a better environment for art creation.

Overall, based on the data collected in this study and the analysis performed for the two hypotheses, we can draw conclusions regarding RQ1 (“Does the immersion and engagement of Virtual Reality provide an adequate environment for asynchronous collaborative art creation?”). The findings of this study indicate that the engagement and immersion in VR are similar to that experienced in RL asynchronous collaborative art creation. Therefore suggesting that the immersion and engagement natural to VR can provide an adequate environment for asynchronous collaborative art creation, much like the traditional RL counterpart. However, we cannot conclude that VR is consistently better than RL in all aspects related to asynchronous collaborative art creation. To draw more definitive conclusions and to address other research questions related to asynchronous collaborative art creation, further research in different contexts and with a larger sample of users is necessary.

5.3.4 Individualized Working Areas in Artistic Collaboration

Our study revealed that artists frequently establish working areas during their painting sessions, for this conclusion we analyzed the maximum distance covered by users in a session, as shown in Table F.2, with a median value of 1.74 and a standard deviation of 0.46.

During the pair-interviews, artists provided insights into their contributions and collaboration dynamics. Participants mentioned intentionally leaving unfinished elements within the artwork for their collaborators to build upon and develop further. This approach fostered a greater sense of shared ownership and facilitated the evolution of ideas within the artwork. Participant P2U1 expressed this perspective, stating, “From my point of view, what I always wanted to do was somehow build upon what was already done and continue the progression”.

Some artists acknowledged moments where they lacked ideas, but still wished to contribute to the final artwork. In such cases, they assumed a supportive role by adding details to their collaborators’ contributions. Participant P3U2 recounted their experience by saying, “I remember making a vortex kind of hastily, but thinking that I would like to see how you (the collaborator) would pick something of mine and improve on it. So I thought, let me leave this here and see if they pick it up or not”.

Based on our findings, we can confirm hypothesis H2.1: “Artists prefer to paint in specific sections

of their artwork, creating their own working areas". While we initially anticipated individualistic and isolated working styles [60], artists also demonstrated a mindful approach to the themes and elements introduced by their collaborators. They drew inspiration from their collaborators' ideas or incorporated their own ideas into the existing context, leading to a harmonious integration of creative contributions.

5.3.5 Branching Motivations and Outcomes

In our study, we found that 37.5% of the users created branches within the collaborative artwork, while another 37.5% were unable to do so due to time constraints or a limited number of sessions. Unexpectedly, the remaining 25% of participants opted for a supportive role, contributing to and building upon their collaborator's ideas.

The motivations behind creating branches varied among the participants. Some users chose to branch out because they felt the collaborator was not aligned with their artistic objectives or the overall theme. By branching out, they sought to maintain their own artistic vision and express their disapproval of the current progress, while retaining a sense of control and reducing their own frustration. On the other hand, other users created branches because they were intrigued by ideas presented by their collaborator but wished to explore a different execution. Additionally, some users created branches when they were dissatisfied with a particular component they had created, leaving it open for their collaborator to potentially build upon.

Throughout the painting sessions, we observed that one branch was created during the second session, while two branches emerged during the third session. Notably, no branches were created in the final session, which may be attributed to the users' awareness that their work could not be continued beyond that point.

Regarding hypothesis H2.2, which refers that "The number of new branches created will increase over the evaluation sessions", our findings support the hypothesis as the number of branches increased over the sessions, except for the final painting session, for the reason explained above. The usage of the branching feature within the collaborative artwork showed the users' desire for creative autonomy and their ability to explore alternative ideas within the project.

During our analysis of the strokes made within the branches, we noticed users tended to paint fewer strokes compared to leaf instances, as indicated in Table 5.2. This can be attributed to users having more well-defined and planned ideas within the branches, leading to fewer errors and, consequently, fewer corrections. Surprisingly, this finding contradicts hypothesis H2.3, which suggested that "The mean number of painting strokes is expected to be higher in newly created branches compared to the asynchronous collaborative branch". We initially expected that the freedom of creative expression within branches would result in increased work, but instead, users demonstrated a higher level of certainty in their artistic actions, resulting in a reduced number of strokes.

Participant P2U1 provided insights into their approach to working within a branch, stating, “For me, the branches would be like ’look at this idea and not that one’. It was never like, I hate your (the collaborator’s) idea and I want to do something completely different because then there wouldn’t be cooperation, right? My idea was always to find a base that you (the collaborator) could work with and wanted to work with, and then I would take your base and see what I could do with it.” This perspective highlights the intention behind the branches as a means of collaboration and where artists aim to build upon each other’s ideas.

5.3.6 Ownership and Idea Exploration in the Creative Process

All participants in the study acknowledged the collaborative nature of the artworks created. However, the level of ownership varied among the participants. Participant P3U2 expressed never feeling individual ownership, noting that their sense of ownership increased with each contribution made, while P3U1 and P4U1 emphasized the shared ownership of the artwork, acknowledging the unique contributions of each collaborator. Focusing on the branching feature, participant P2U2 experienced a heightened sense of shared collaboration when working on a new branch, as the entire basis of the work revolved around their collaborator’s contributions.

The participants’ perspectives reflected a collaborative mindset, where the shared artworks created by both collaborators modified their sense of ownership. In terms of idea exploration, the participants demonstrated a willingness to embrace and appreciate their collaborator’s contributions. They also expressed openness to their collaborator erasing or modifying parts of their own drawings, highlighting a sense of receptiveness and curiosity. This leads us to believe that the use of VR for asynchronous collaboration with the version control implementation enabled artists to explore different ideas for an art piece, fostering an environment of experimentation and creative exchange.

The results of the hypotheses H2.1, H2.2 and H2.3 provide insights into RQ2 (“How does the use of Virtual Reality for asynchronous collaboration impact artists’ sense of ownership over the creative process? To what extent do artists explore different ideas for an art piece?”). Hypothesis H2.1 yielded a positive outcome, as discussed in Section 5.3.4, indicating that artists created their own working areas within the artwork while being mindful of the collaborative aspect. This aligns with a positive answer to RQ2, as it demonstrates that artists were able to explore their unique visions while acknowledging the collaborative nature of the artwork. Similarly, the confirmation of hypothesis H2.2, as discussed in Section 5.3.5, also supports a positive answer to RQ2. As users found the branching feature important for their creative autonomy and to express alternative ideas within the same art project. Although hypothesis H2.3 was refuted, as explained in Section 5.3.5, this does not necessarily imply a negative answer to RQ2. The refutation was attributed to unexpected factors, such as the users’ focus on a specific planned idea which led to less painting strokes. Therefore, the impact of VR on artists’ sense of ownership and

idea exploration remains positive.

In conclusion, the use of VR for asynchronous collaboration appears to have positively impacted artists' sense of ownership over the creative process. It fostered a shared ownership mindset among participants, where they valued and embraced their collaborator's contributions. Moreover, VR facilitated idea exploration by providing a platform for artists to experiment comfortably and collaborate without overwriting previous work, leading to a more dynamic and engaging creative experience.

6

Conclusion

Contents

The proposed platform aimed to address the challenges associated with collaborative art creation and explore the potential of VR in the context of asynchronous artistic collaboration. By developing a VR application with a version control system, our aim was to provide contributing artists with an alternate approach to collaboration, while fostering idea exploration and minimizing creative conflicts.

Through the evaluation of two user tests and analysis of the gathered data, we have gained valuable insights into the effectiveness of our proposed solution. Our findings reveal similarities between the VR and RL environments in terms of the level of immersion and engagement experienced by artists, indicating that VR can provide an adequate environment for asynchronous collaborative art creation. Furthermore, we observed that the utilization of VR positively influenced users' sense of ownership over the creative process and enhanced their comfort in exploring new ideas.

By combining the advantages of VR with the flexibility of asynchronous collaboration and version control, our solution offers a way for artists to collaborate while respecting each other's artistic freedom. The findings of this study contribute to the field of collaborative art creation and pave the way for further exploration and innovation in this domain.

6.1 Exploratory Study on Synchronous Artwork Creation

The application developed for this thesis has undergone an iterative process to refine the proposed solution based on user feedback. The iteration discussed in this section, although not subjected to user testing, represents an important milestone in the project's development. Its primary objective was to implement synchronous collaboration with Ubiq [43], enabling additional features to enhance existing collaborations. Furthermore, urgent improvements were made to the branching interface to address specific issues raised by users.

Through this iterative design process and with user feedback from the second user test, this thesis has resulted in the creation of an artifact. This section provides an overview of the final iteration, highlighting the enhancements made and the key considerations taken into account during the development process.

6.1.1 Branching Visualization Correction

When users accessed the branching visualization in walls other than the initial one at the beginning of the user test, a display issue occurred where the instances and their details appeared rotated and flipped, as depicted in Figure 6.1. This not only caused confusion but also resulted in errors when selecting instances, which took users some time to comprehend. To solve this issue, we conducted a review of the code and performed extensive testing to ensure the proper functioning of the visualization feature.

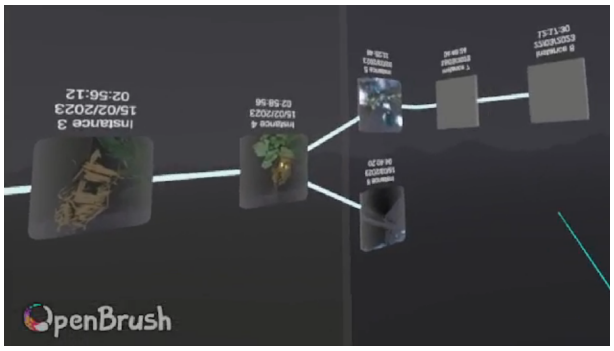


Figure 6.1: Frame from recorded painting session of user P3U2, highlighting the occurrence of the branching visualization error.

Figure 6.2: Ubiq room information implemented in the Tools UI. (Room Name: Join Code)

Figure 6.3: Ubiq Join Room UI: The top section displays the rooms available on the local device for asynchronous collaboration, while the bottom section shows the online rooms with active users for synchronous collaboration.

6.1.2 Synchronous Collaboration

Enabling synchronous collaboration in our asynchronous system was made possible by leveraging Ubiq's design, which primarily focuses on synchronous solutions.

In the default rooms of Ubiq, artists can collaborate in real-time, however these rooms lack persistence, meaning they do not retain data beyond the current session. To support synchronous collaboration in our system, we adapted Ubiq's functionality to maintain the works created during asynchronous collaboration. By leveraging both a Ubiq server and the local file storage, we successfully simulated room persistence, ensuring the preservation and conservation of room data. This crucial feature allowed for the quick and accurate reopening of specific rooms when needed, enabling users to access and work on their previous projects without losing any progress or version tree information. The Node.js [61] server responsible for generating and managing the Ubiq rooms can be found in the release of Ubiq version 0.1.1. [44]

Upon launching the application, the server immediately generates a new room, and its information is

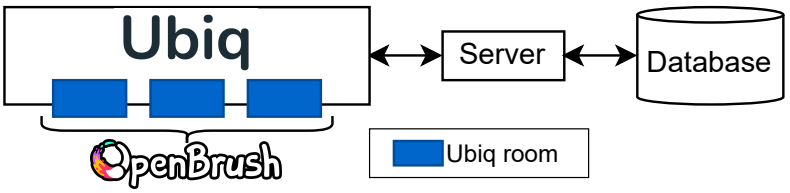


Figure 6.4: Proposed architecture for future work.

displayed on the Tools panel of the user's left-hand controller, as shown in Figure 6.2. This information is presented in the format of "Room Name: Join Code", serving as an important means for users to communicate the Join Code of the room they are currently in so others can join them. All available joinable rooms are listed in the "Join Room" UI, as depicted in Figure 6.3, where Local Rooms are identified by their Room Name, while Online Rooms are identified by the Join Code.

6.2 Future Work

After the third iteration of the system, our project shows certain limitations that can be addressed in future work. In addition to technical improvements to the system, there are research questions that can be explored to advance the understanding and practice of asynchronous collaborative art creation.

6.2.1 Technical Improvements

One significant area for improvement is the implementation of an online server and database, as represented in Figure 6.4. The current reliance on local files introduces the risk of file loss and version desynchronization among collaborators. Transitioning to an online infrastructure would enhance data management and ensure seamless collaboration.

Another aspect that requires consideration is the loading of instances in the current branching interface. Currently, a different selection ray is used compared to the other interface menus, resulting in moments where both rays are active simultaneously, which can cause confusion for the user. Unifying the selection rays or changing the method for selection would enhance the user experience. Additionally, while the current branching interface functions well for small projects with a limited number of collaborators, scalability becomes a challenge when considering community contributions. Future work should explore alternative approaches to accommodate a larger number of collaborators and facilitate community-based projects.

Addressing these limitations and implementing the proposed future work would further improve the functionality, usability, and scalability of the system, contributing to a more versatile and user-friendly system for collaborative art creation.

6.2.2 Research on Artistic Interaction

In addition to the technical improvements, there are research questions that can be pursued to further advance the field of asynchronous collaborative art creation:

- What are the most effective interface designs and interaction techniques for facilitating communication, idea sharing, and synchronization among collaborating artists in a VR-based asynchronous collaboration? Exploring interface designs and interaction techniques that balance the anonymity desired by artists while enabling effective synchronization with collaborators can enhance the collaborative experience and its outcomes.
- How is ownership of asynchronous artwork creation affected in large groups and art communities? Investigating the dynamics of ownership, creative freedom, and collaboration within larger groups can provide insights into the challenges and opportunities of scaling up asynchronous collaborative art projects.
- How does the usage of versioning evolve over longer periods of collaboration? Conducting extended evaluations can reveal how artists' engagement with version control and their exploration of new ideas change over time.

By addressing these research questions, we can advance our understanding of artistic interactions and perspectives of asynchronous collaborative art creation. The findings from these studies can inform the development of improved techniques and methodologies, with the goal of fostering the growth of art communities and facilitating conflict-free collaborations.

Bibliography

[1] M. Laal and S. Ghodsi, "Benefits of collaborative learning," *Procedia-social and behavioral sciences*, vol. 31, pp. 486–490, 2012.

[2] E. Lai, "Collaboration: A literature review," *Pearson Publisher. Retrieved November*, vol. 11, p. 2016, 2011.

[3] S. Bigliazzi, *Collaboration in the Arts from the Middle Ages to the Present*. Routledge, 2017.

[4] Gagosian, "Jean-Michel Basquiat and Andy Warhol: Olympic rings, Davies Street, London, June 19–August 11, 2012," https://gagosian.com/exhibitions/2012/jean-michel-basquiat-and-andy-warhol-olympic-rings/, Apr 2018, Accessed: 2023-04-29.

[5] F. Gallery, "Bernd & Hilla Becher," https://fraenkelgallery.com/artists/bernd-and-hilla-becher, Jan 2023, Accessed: 2023-04-29.

[6] H. Lydiate, "Collaborative Works," https://artquest.org.uk/artlaw-article/collaborative-works/, 2004, Accessed: 2022-11-16.

[7] B. Sherwin, "The legal side of artistic collaboration," https://theartedge.faso.com/blog/70701/the-legal-side-of-artistic-collaboration, Jan 2014, Accessed: 2022-11-16.

[8] O. Friedman, "Questions and potential answers about ways ownership and art matter for one another," *Empirical Studies of the Arts*, vol. 38, no. 1, p. 119–127, 2019.

[9] C. Paul, *Digital art*. Thames & Hudson London, 2003, vol. 14.

[10] F. Spampinato and V. Catricalà, "Contemporary Art and Virtual Reality: New Conditions of Viewership," *Cinergie–Il Cinema e le altre Arti*, no. 19, pp. 121–133, 2021.

[11] S. Obeid and H. Demirkan, "The influence of virtual reality on design process creativity in basic design studios," *Interactive Learning Environments*, pp. 1–19, 2020.

[12] Y.-S. Chang, C.-H. Chou, M.-J. Chuang, W.-H. Li, and I.-F. Tsai, “Effects of virtual reality on creative design performance and creative experiential learning,” *Interactive Learning Environments*, vol. 31, no. 2, pp. 1142–1157, 2023.

[13] D. Maloney and G. Freeman, “Falling asleep together: What makes activities in social virtual reality meaningful to users,” in *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, 2020, pp. 510–521.

[14] C. Wang, M. Sakashita, U. Ehsan, J. Li, and A. Won, “Again, Together: Socially Reliving Virtual Reality Experiences When Separated,” in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, ser. CHI ’20. New York, NY, USA: Association for Computing Machinery, 2020, p. 1–12.

[15] G. Freeman and D. Acena, “Hugging from A Distance: Building Interpersonal Relationships in Social Virtual Reality,” in *ACM International Conference on Interactive Media Experiences*, 2021, pp. 84–95.

[16] Y. Kim and H. Lee, “Falling in love with virtual reality art: a new perspective on 3D immersive virtual reality for future sustaining art consumption,” *International Journal of Human–Computer Interaction*, vol. 38, no. 4, pp. 371–382, 2022.

[17] M. Miessen, *The Nightmare of Participation*. Sternberg Press, 2010.

[18] P. Livingston and C. Archer, “Artistic collaboration and the completion of works of art,” *The British Journal of Aesthetics*, vol. 50, no. 4, pp. 439–455, 2010.

[19] C. Roa, “Artistic collaboration and conflict and some advice from experienced professionals,” https://www.theartblog.org/2018/07/artistic-collaboration-and-conflict-and-some-advice-from-experienced-professionals/, Jul 2018, Accessed: 2023-04-17.

[20] B. Lee, “Analysis of digital art content created through collaboration,” *Archives of Design Research*, vol. 30, no. 4, pp. 17–24, 2017.

[21] A. Figliuzzi, “Cryptocurrency as a Positive Force of Change in the Classical Music Industry,” *Student Publications, Presentations, and Projects*, 2021.

[22] S. Blythe and E. Powers, *Looking at Dada*. The Museum of Modern Art, 2006.

[23] B. André, *Le surrealisme et la peinture: Nouv. Ed. rev. Corr.* Gallimard, 1965.

[24] B. Sherwin, “Collaboration in art – mutual respect, mutual work, mutual exposure,” https://fineartviews.com/blog/34275/collaboration-in-art-mutual-respect-mutual-work-mutual-exposure, Aug 2011, Accessed: 2022-05-27.

[25] E. De Wachter, *Co-Art: Artists on Creative Collaboration*. Phaidon Press, 2017.

[26] RadicalMedia, “The Johnny Cash Project,” https://www.radicalmedia.com/work/the-johnny-cash-project/, Jan 2018, Accessed: 2023-04-18.

[27] M. Barth, J. Pacheco, and C. Pinheiro, “Interação, engajamento e crowdsourcing: um estudo do caso The Johnny Cash Project,” *Comunicação & Informação*, vol. 18, no. 1, p. 76–96, Jun 2015.

[28] Communication Arts, “The 1000 Journals Project book,” https://www.commarts.com/project/16788/the-1000-journals-project-book, Accessed: 2023-06-18.

[29] C. Pidel and P. Ackermann, “Collaboration in virtual and augmented reality: a systematic overview,” in *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 2020, pp. 141–156.

[30] Y. Zhang, H. Nguyen, N. Ladeveze, C. Fleury, and P. Bourdot, “Virtual Workspace Positioning Techniques during Teleportation for Co-located Collaboration in Virtual Reality using HMDs,” in *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2022, pp. 674–682.

[31] D. Beck, “Augmented and virtual reality in education: Immersive learning research,” *Journal of Educational Computing Research*, vol. 57, no. 7, pp. 1619–1625, 2019.

[32] Adobe, “Oculus Medium,” https://www.adobe.com/products/medium.html, Accessed: 2022-05-15.

[33] Masterpiece Studio, “MaterpieceVR,” https://masterpiecestudio.com/, Accessed: 2022-05-15.

[34] J. Knispel and F. Bullock, “Collaborative VR painting in web browsers,” in *SIGGRAPH Asia 2017 VR Showcase*, 2017, pp. 1–2.

[35] J. Kemp, “Practical Ethics v3.0: Version Control,” *Art and Material: The division of labour*, 2021.

[36] M. Fischer, “A proposal for a virtual reality museum for virtual reality art,” *MW17*, vol. 2, 2017.

[37] Z. Lu, P. Guerrero, N. Mitra, and A. Steed, “Open3D: crowd-sourced distributed curation of city models,” in *Proceedings of the 21st International Conference on Web3D Technology*, 2016, pp. 87–94.

[38] Snowtrack, “SnowFS,” https://www.snowtrack.io/, Accessed: 2022-05-12.

[39] Blender Online Community, “Blender - a 3D modelling and rendering package,” http://www.blender.org, Blender Foundation, 2018, Accessed: 2022-05-22.

[40] G. Nelson and S. Ellis, “The history and impact of digitization and digital data mobilization on biodiversity research,” *Philosophical Transactions of the Royal Society B*, vol. 374, no. 1763, p. 20170391, 2019.

[41] R. Merkle, “A digital signature based on a conventional encryption function,” in *Conference on the theory and application of cryptographic techniques*. Springer, 1987, pp. 369–378.

[42] Unity Technologies, “Unity,” https://unity.com/, Accessed: 2023-05-06.

[43] S. Friston, B. Congdon, D. Swapp, L. Izzouzi, K. Brandstätter, D. Archer, O. Olkkonen, F. Thiel, and A. Steed, “Ubiq: A System to Build Flexible Social Virtual Reality Experiences,” in *Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology*, 2021, pp. 1–11.

[44] UCL-VR, “Release v0.1.1 · UCL-VR/Ubiq,” https://github.com/UCL-VR/ubiq/releases/tag/v0.1.1, Oct 2021, Accessed: 2022-07-24.

[45] R. Vallbona and B. Pérez, “Ilustración digital y realidad virtual: un marco de investigación para el aprendizaje inclusivo a través de herramientas de software libre,” *GKA VISUAL 2021*, pp. 13–16, 2021.

[46] Icosa Foundation, “Release v0.3.0 flying, filming, and fixes! ICOSA-Gallery/open-brush,” https://github.com/icosa-gallery/open-brush/releases/tag/0.3.0, Apr 2021, Accessed: 2023-05-06.

[47] Valve Corporation, “SteamVR on Steam,” https://store.steampowered.com/app/250820/SteamVR/, Apr 2016, Accessed: 2023-05-06.

[48] Unity Technologies, “Unity 2019.4.25f1,” https://unity.com/releases/editor/whats-new/2019.4.25, Apr 2021, Accessed: 2023-05-06.

[49] D. Crockford and C. Morningstar, “Standard ECMA-404 The JSON Data Interchange Syntax,” Dec 2017.

[50] Y. Shafranovich, “Common Format and MIME Type for Comma-Separated Values (CSV) Files,” https://www.rfc-editor.org/info/rfc4180, Oct. 2005, Accessed: 2023-04-14.

[51] J. Brooke, “SUS: A quick and dirty usability scale,” *Usability Eval. Ind.*, vol. 189, Nov 1995.

[52] Student, “The probable error of a mean,” *Biometrika*, vol. 6, no. 1, pp. 1–25, 1908.

[53] M. Schrepp, A. Hinderks, and J. Thomaschewski, “Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S),” *International Journal of Interactive Multimedia and Artificial Intelligence*, vol. 4, p. 103, Jan 2017.

[54] Icosa Foundation, “Icosa,” https://beta.icosa.gallery/, Accessed: 2023-01-24.

[55] KhronosGroup, “KhronosGroup/gltf: glTF – Runtime 3D Asset Delivery,” https://github.com/KhronosGroup/glTF, Accessed: 2023-03-14.

[56] B. Witmer and M. Singer, “Measuring presence in virtual environments: A presence questionnaire,” *Presence*, vol. 7, no. 3, pp. 225–240, 1998.

[57] Y. Dodge, *The Concise Encyclopedia of Statistics*. Springer New York, 2008, pp. 502–505.

[58] Zetland, “Good Tape,” https://www.mygoodtape.com/, Accessed: 2023-03-26.

[59] Snapchat For Business, “Augmented Reality Is Here — and It’s More Immersive Than Traditional Advertising [KSA],” https://forbusiness.snapchat.com/blog/augmented-reality-is-here-and-its-more-immersive-than-traditional-advertising-ksa, Accessed: 2022-10-26.

[60] The Swedish Arts Grants Committee, “A study of artists’ working environment,” https://www.konstnarsnamnden.se/pdf/A%20study%20of%20artists%20working%20environment.pdf, Aug 2018, Accessed: 2023-05-18.

[61] OpenJS Foundation, https://nodejs.org/en, Accessed: 2023-05-22.

Collection of User Artworks

A.1 Asynchronous Environment and Branching Interface Preference User Evaluation

A.1.1 Real-life Artworks

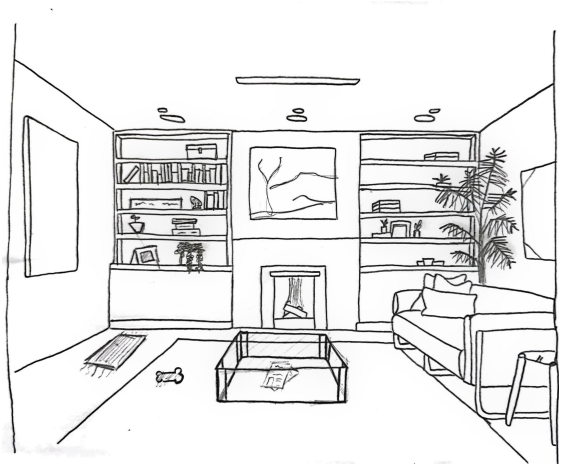


Figure A.1: Asynchronous collaborative RL artwork created by user 1.

Figure A.2: Asynchronous collaborative RL artwork created by user 2.

Figure A.3: Asynchronous collaborative RL artwork created by user 3.

Figure A.4: Asynchronous collaborative RL artwork created by user 4.

Figure A.5: Asynchronous collaborative RL artwork created by user 5.

Figure A.6: Asynchronous collaborative RL artwork created by user 6.

Figure A.7: Asynchronous collaborative RL artwork created by user 7.

Figure A.8: Asynchronous collaborative RL artwork created by user 8.

A.1.2 Virtual Reality Artworks

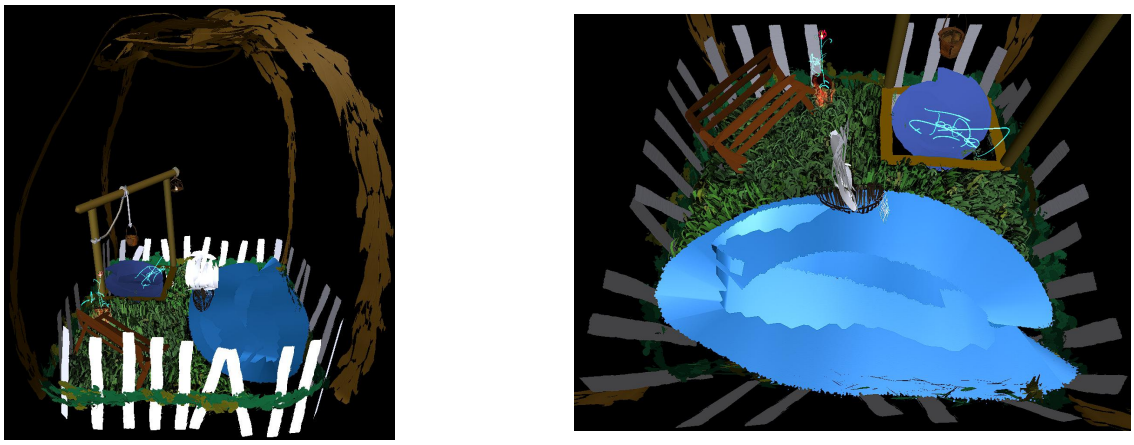


Figure A.9: Asynchronous collaborative VR artwork created by user 1. On the left, the side view and on the right an aerial view of the artwork.

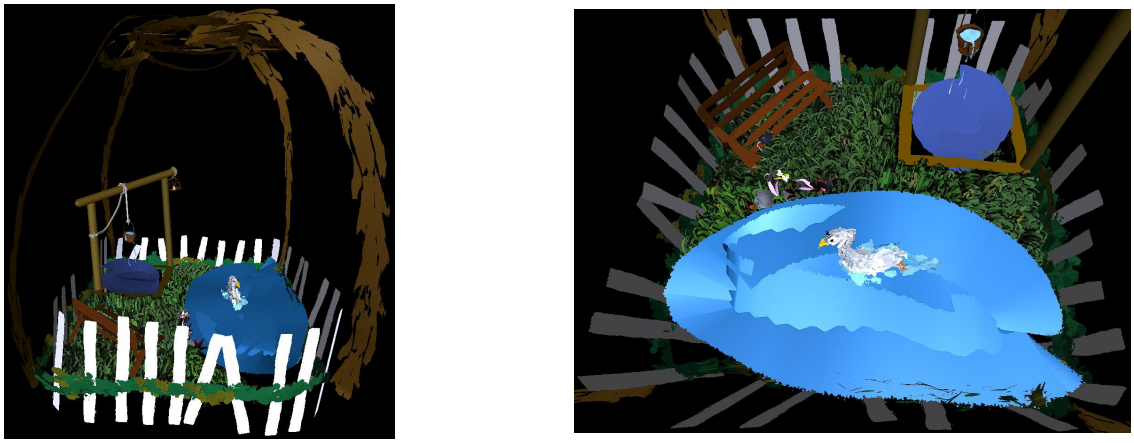


Figure A.10: Asynchronous collaborative VR artwork created by user 2. On the left, the side view and on the right an aerial view of the artwork.

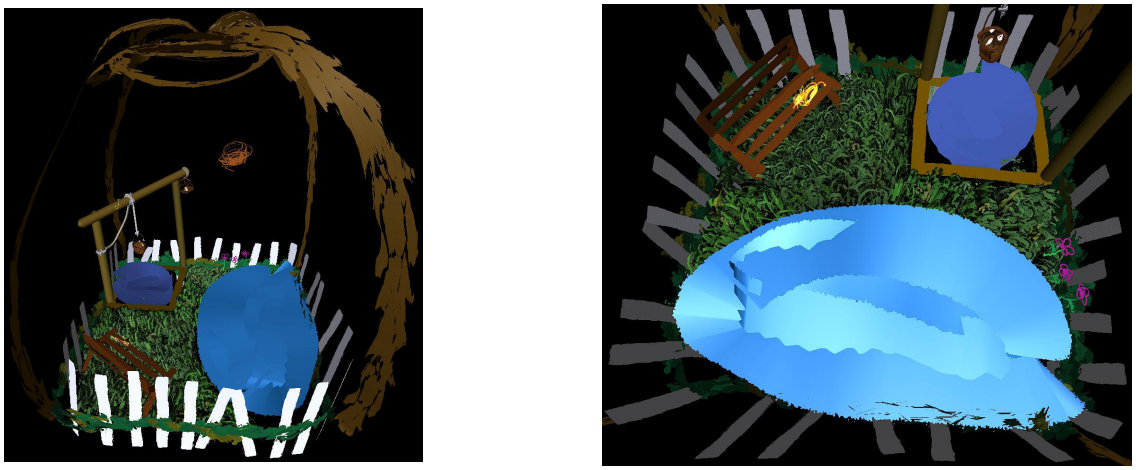


Figure A.11: Asynchronous collaborative VR artwork created by user 3. On the left, the side view and on the right an aerial view of the artwork.

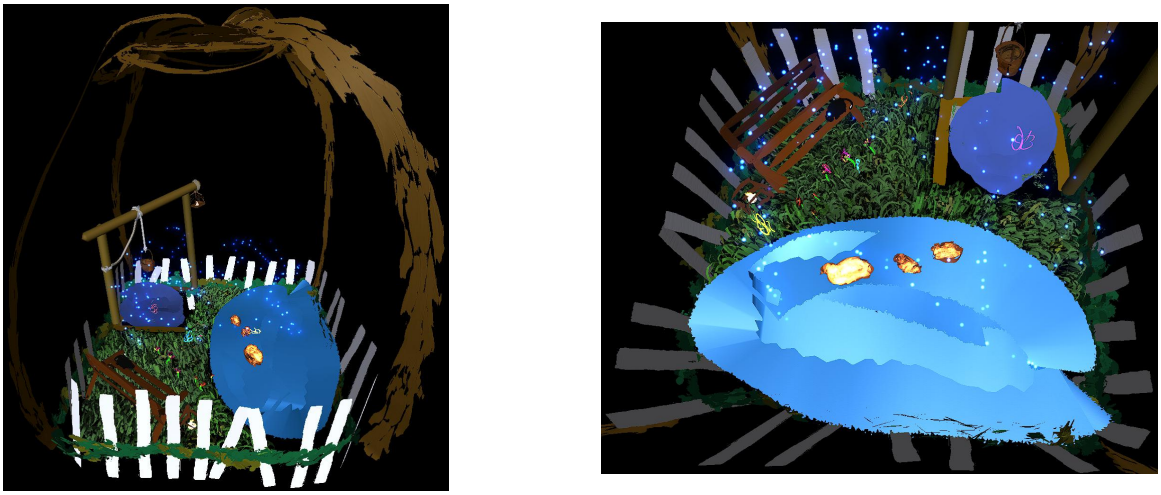


Figure A.12: Asynchronous collaborative VR artwork created by user 4. On the left, the side view and on the right an aerial view of the artwork.

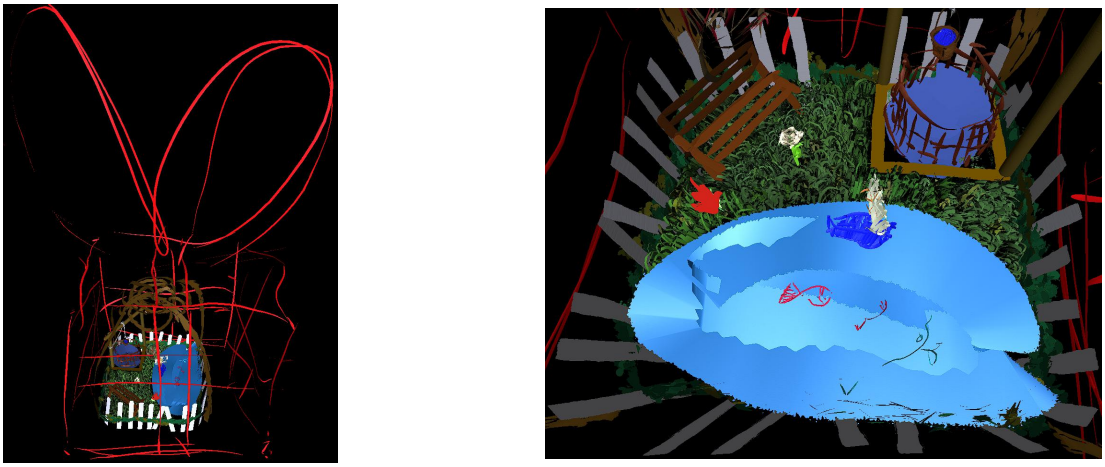


Figure A.13: Asynchronous collaborative VR artwork created by user 5. On the left, the side view and on the right an aerial view of the artwork.

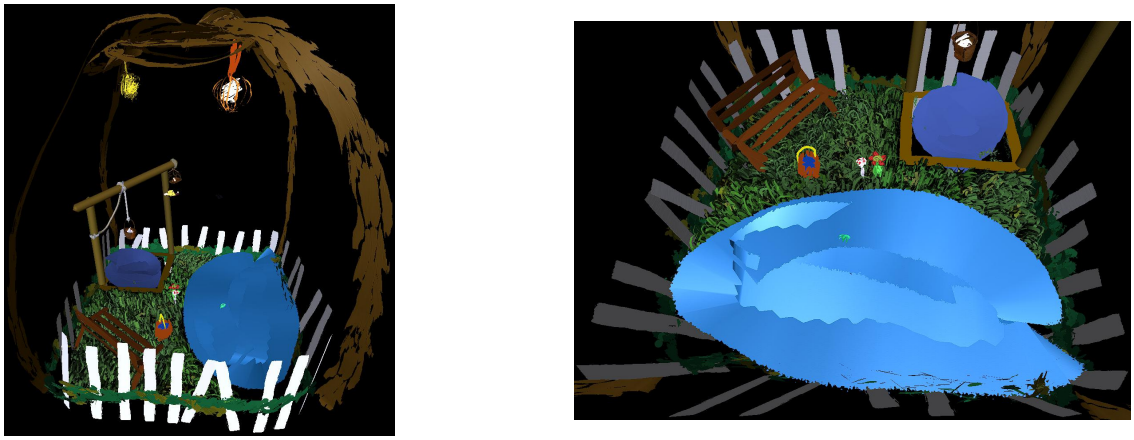


Figure A.14: Asynchronous collaborative VR artwork created by user 6. On the left, the side view and on the right an aerial view of the artwork.

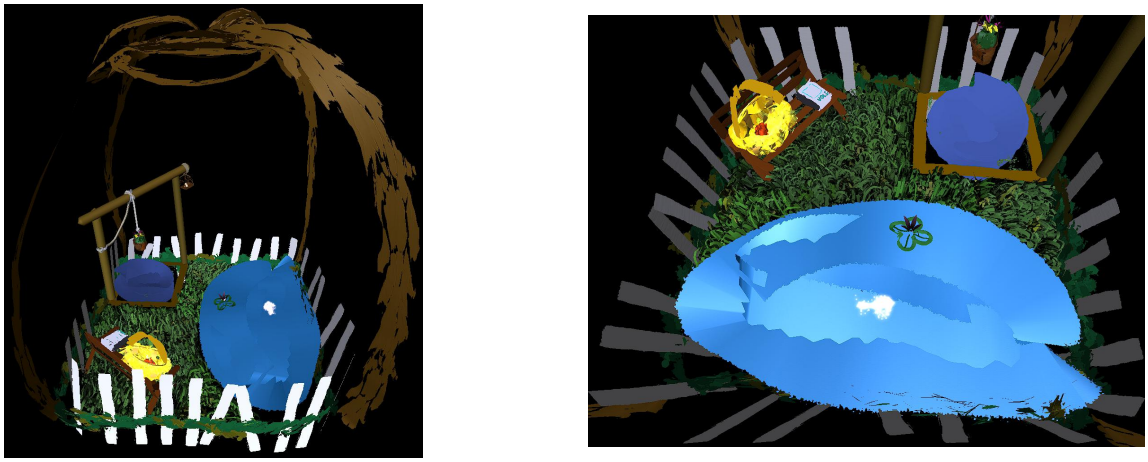


Figure A.15: Asynchronous collaborative VR artwork created by user 7. On the left, the side view and on the right an aerial view of the artwork.

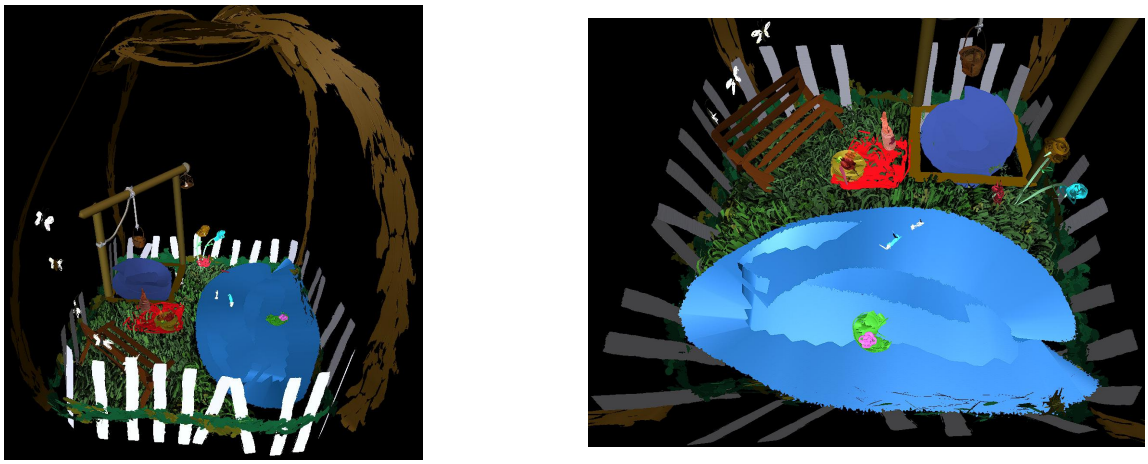


Figure A.16: Asynchronous collaborative VR artwork created by user 8. On the left, the side view and on the right an aerial view of the artwork.

A.2 Continuous Asynchronous Collaboration User Evaluation

A.2.1 VR Artworks by Pair 1

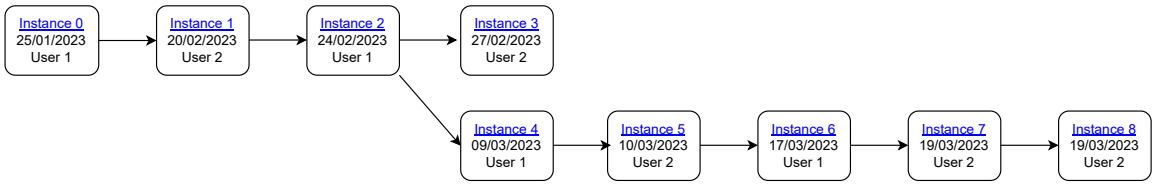


Figure A.17: Tree visualization with the sequence of the instances created by the first pair of users. Each instance includes the name, the date it was created, and the user who created it.

Figure A.18: Instance 0 (root) of VR art project created by user 1.

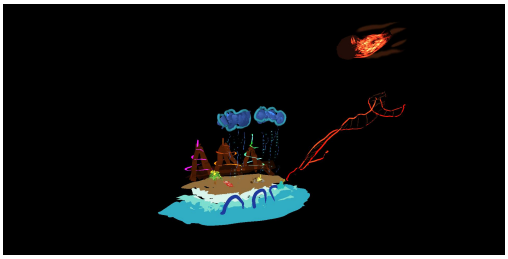


Figure A.19: Instance 1 of VR art project created by user 2.

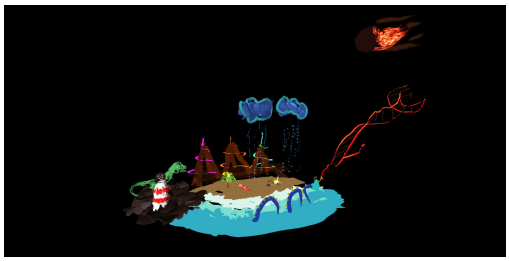


Figure A.20: Instance 2 of VR art project created by user 1.

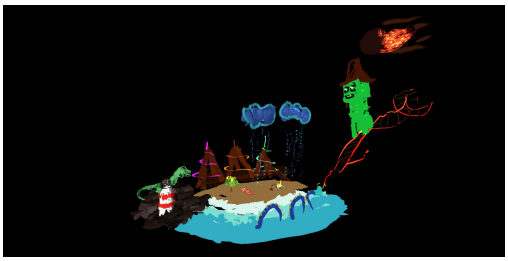


Figure A.21: Instance 3 of VR art project created by user 2.

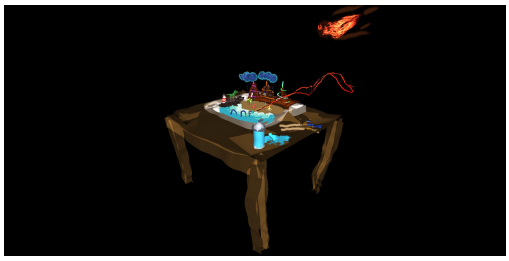


Figure A.22: Instance 4 of VR art project created by user 1.

Figure A.23: Instance 5 of VR art project created by user 2.

Figure A.24: Instance 6 of VR art project created by user 1.

Figure A.25: Instance 7 and 8 of VR art project created by user 2.

A.2.2 VR Artworks by Pair 2

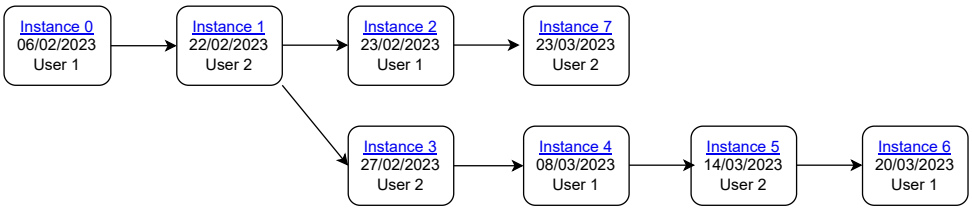


Figure A.26: Tree visualization with the sequence of the instances created by the second pair of users. Each instance includes the name, the date it was created, and the user who created it.

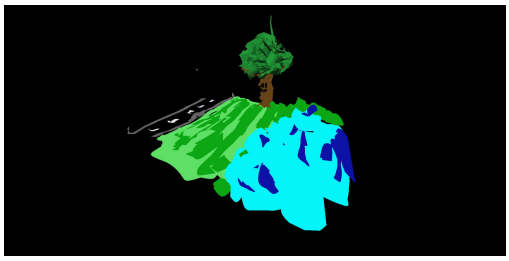


Figure A.27: Instance 0 (root) of VR art project created by user 1.

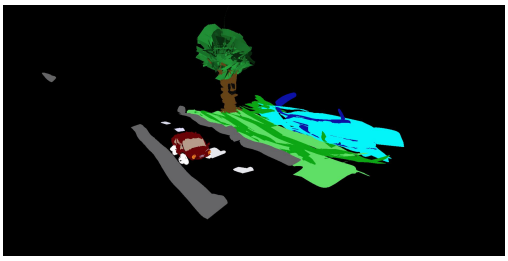


Figure A.28: Instance 1 of VR art project created by user 2.

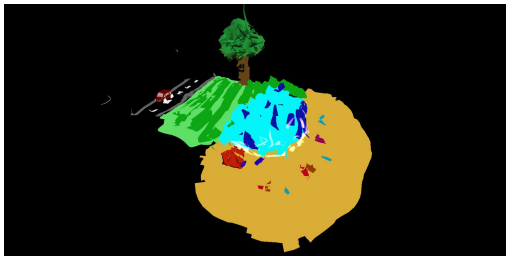


Figure A.29: Instance 2 of VR art project created by user 1.

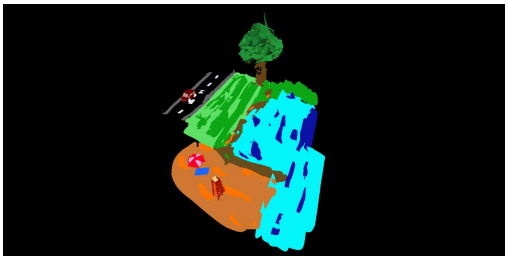


Figure A.30: Instance 3 of VR art project created by user 2.

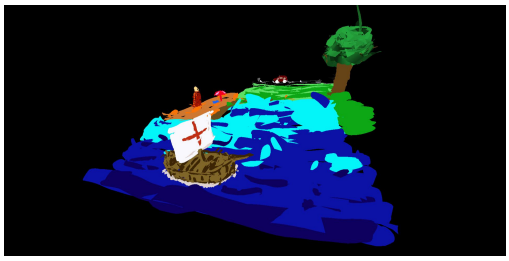


Figure A.31: Instance 4 of VR art project created by user 1.

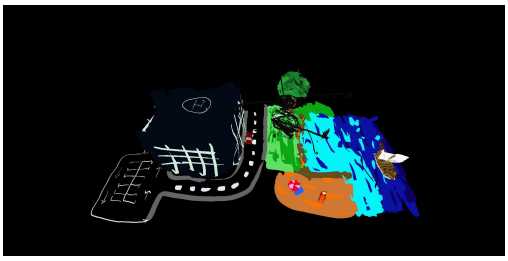


Figure A.32: Instance 5 of VR art project created by user 2.

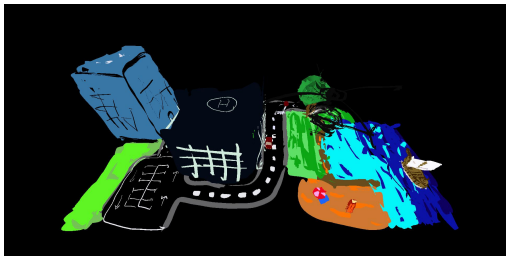


Figure A.33: Instance 6 of VR art project created by user 1.

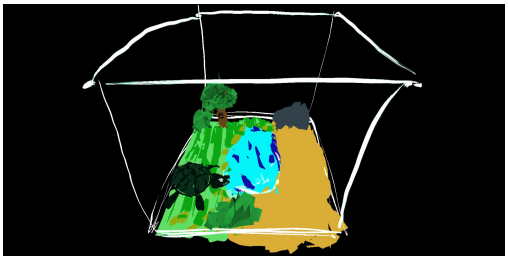


Figure A.34: Instance 7 of VR art project created by user 2.

A.2.3 VR Artworks by Pair 3

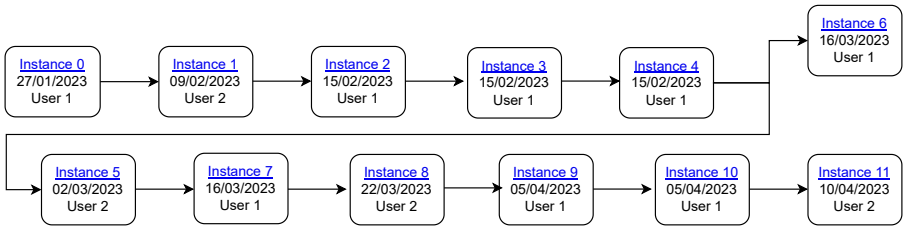


Figure A.35: Tree visualization with the sequence of the instances created by the third pair of users. Each instance includes the name, the date it was created, and the user who created it.

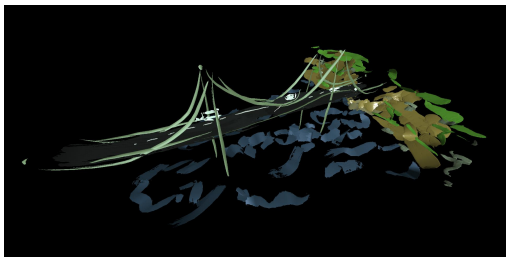


Figure A.36: Instance 0 (root) of VR art project created by user 1.

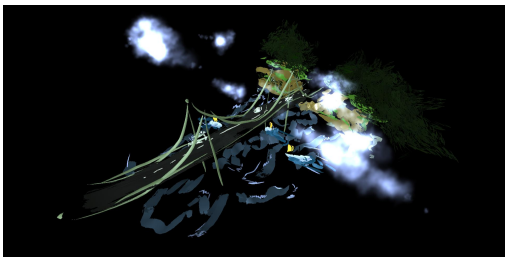


Figure A.37: Instance 1 of VR art project created by user 2.

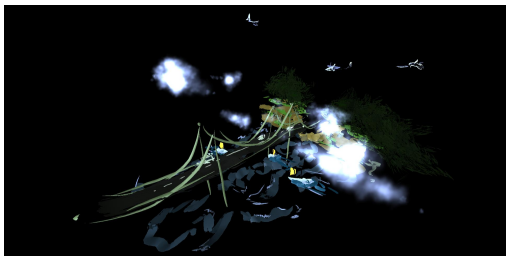


Figure A.38: Instance 2 of VR art project created by user 1.

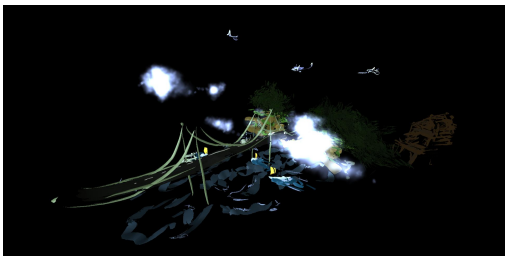


Figure A.39: Instance 3 of VR art project created by user 1.

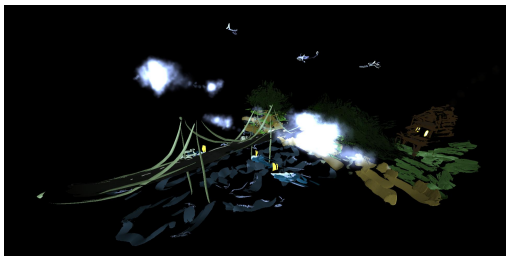


Figure A.40: Instance 4 of VR art project created by user 1.

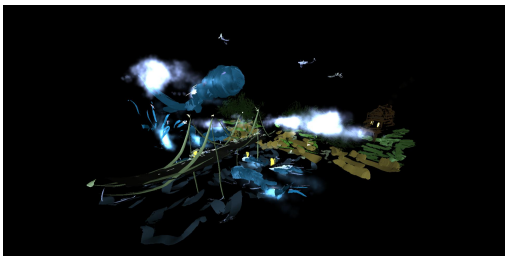


Figure A.41: Instance 5 of VR art project created by user 2.

Figure A.42: Instance 6 of VR art project created by user 1.

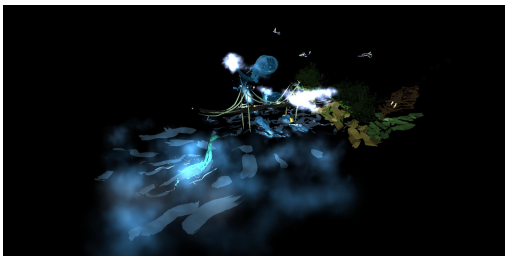


Figure A.43: Instance 7 of VR art project created by user 1.

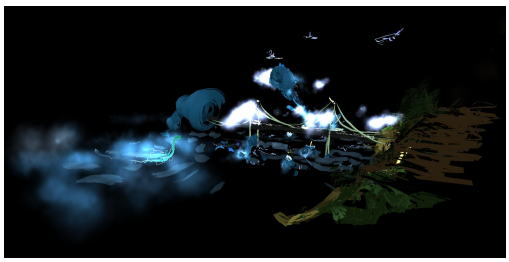


Figure A.44: Instance 8 of VR art project created by user 2.

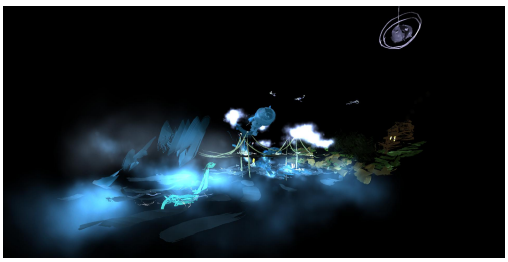


Figure A.45: Instance 9 of VR art project created by user 1.

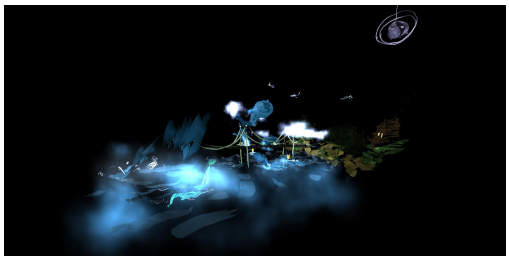


Figure A.46: Instance 10 of VR art project created by user 1.

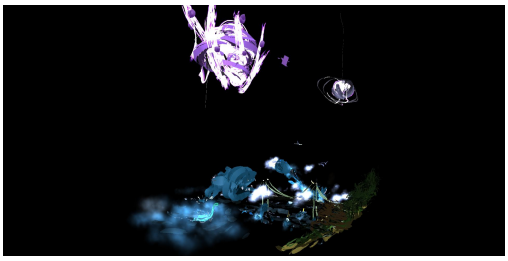


Figure A.47: Instance 11 of VR art project created by user 2.

A.2.4 VR Artworks by Pair 4

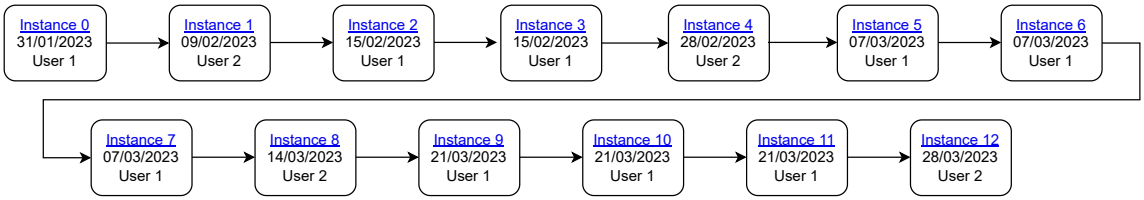


Figure A.48: Tree visualization with the sequence of the instances created by the fourth pair of users. Each instance includes the name, the date it was created, and the user who created it.

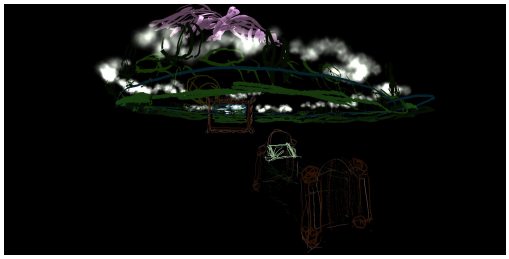


Figure A.49: Instance 0 (root) of VR art project created by user 1.

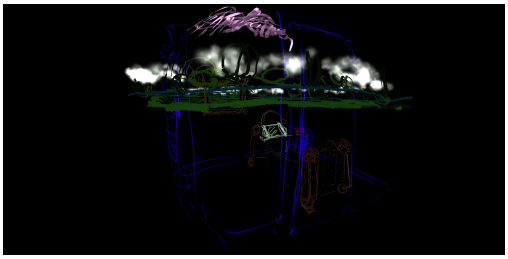


Figure A.50: Instance 1 of VR art project created by user 2.

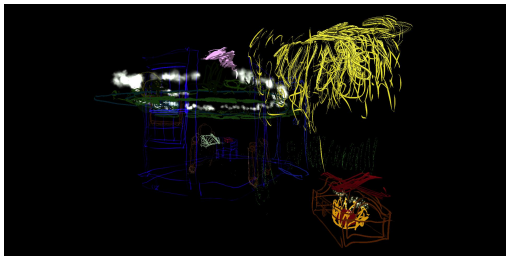


Figure A.51: Instance 2 of VR art project created by user 1.

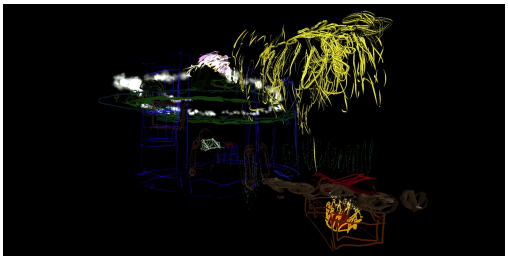


Figure A.52: Instance 3 of VR art project created by user 1.

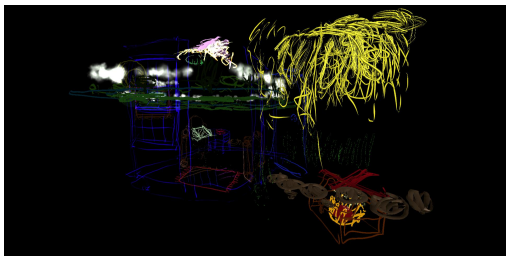


Figure A.53: Instance 4 of VR art project created by user 2.

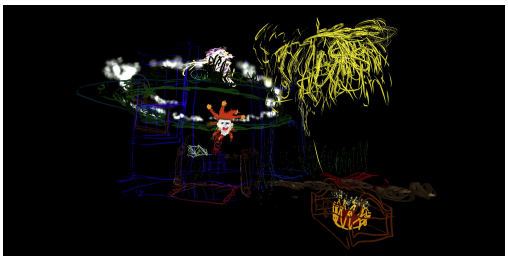


Figure A.54: Instance 5 and 6 of VR art project created by user 1.

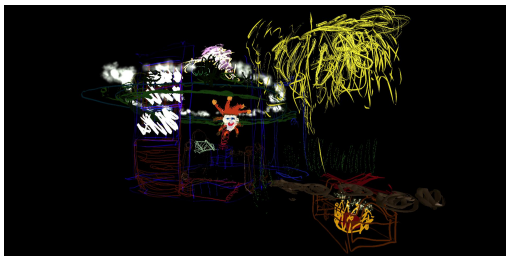


Figure A.55: Instance 7 of VR art project created by user 1.

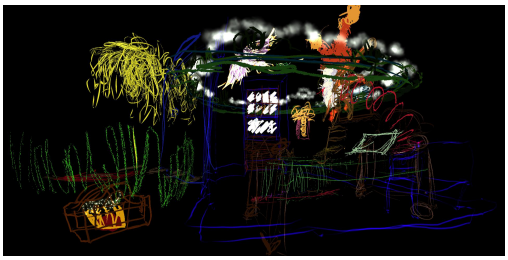


Figure A.56: Instance 8 of VR art project created by user 2.

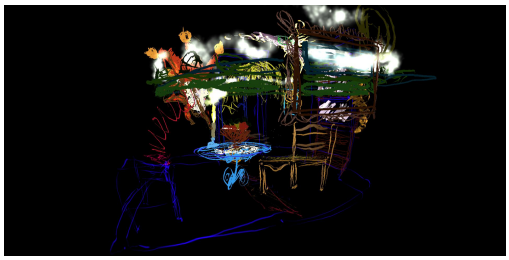


Figure A.57: Instance 9 of VR art project created by user 1.

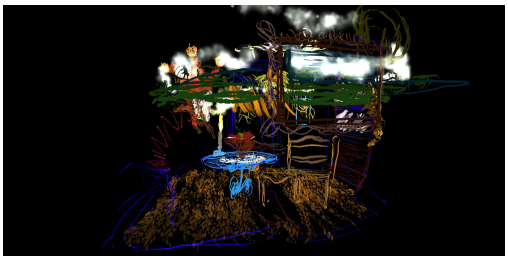


Figure A.58: Instance 10 of VR art project created by user 1.

Figure A.59: Instance 11 of VR art project created by user 1.

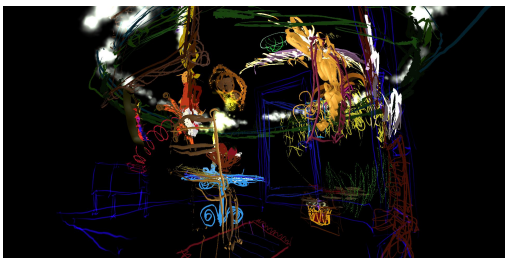


Figure A.60: Instance 12 of VR art project created by user 2.

B

First User Test - RL and VR Environments Questionnaire

Master Thesis Asynchronous Collaborative Art Creation Questionnaire 1

This survey intends to study if the features of Virtual Reality provide an adequate environment for asynchronous collaborative art creation.

Now that you have completed the real-life and VR artworks, you can answer this questionnaire with your personal opinions and feelings.
It's expected to take about 8 minutes.

Thank you for your participation.

* Indicates required question

Demographic questions and additional information

User number *

Your answer

Gender *

- ◯ Male
- ◯ Female
- ◯ Prefer not to say
- ◯ Other:

Age *

- ○ 18 - 21 years old
- ○ 22 - 25 years old
- ○ 26 - 30 years old
- ○ 31 - 40 years old
- ○ 41+ years old

Highest level of education completed *

- ○ High School
- ○ Licentiate degree or Bachelor's Degree
- ○ Master's Degree
- ○ Ph.D. or higher

Level of experience as an artist *

- ☐ Hobby or amateur level
- ☐ Academic degree in fine arts
- ☐ Work experience
- ☐ Other:

Level of experience with Virtual Reality *

- ○ A lot (used VR more than five times)
- ○ Little (used VR one to four times)
- ○ None (no experience with VR)

Questions related to the real-life artwork

These questions are focused on the experience related to the **real-life artwork.** Please answer the following questions while thinking about that experience.

From 1 (completely disagree) to 5 (completely agree) rate this sentences. *

	1	2	3	4	5
By completing the artwork, I was collaborating with other artists.	○	○	○	○	○
I felt close to the original artist of the artwork.	○	○	○	○	○
I understood the objectives given to me.	○	○	○	○	○
I found the objectives easy to complete.	○	○	○	○	○
I was in control of the changes made to the artwork.	○	○	○	○	○
My interactions with the artwork were natural.	○	○	○	○	○
The surrounding environment was ideal for art creation.	○	○	○	○	○
I was immersed in completing the artwork.	○	○	○	○	○
I felt engaged to complete the artwork.	○	○	○	○	○
I had fun while working on the artwork.	○	○	○	○	○
I was confortable during this collaborative work.	○	○	○	○	○
The finished artwork is original.	○	○	○	○	○
The finished artwork is elegant.	○	○	○	○	○
The finished artwork was better with collaboration.	○	○	○	○	○
I imagined different possibilities that I could try in this artwork.	○	○	○	○	○

Questions related to the virtual reality artwork

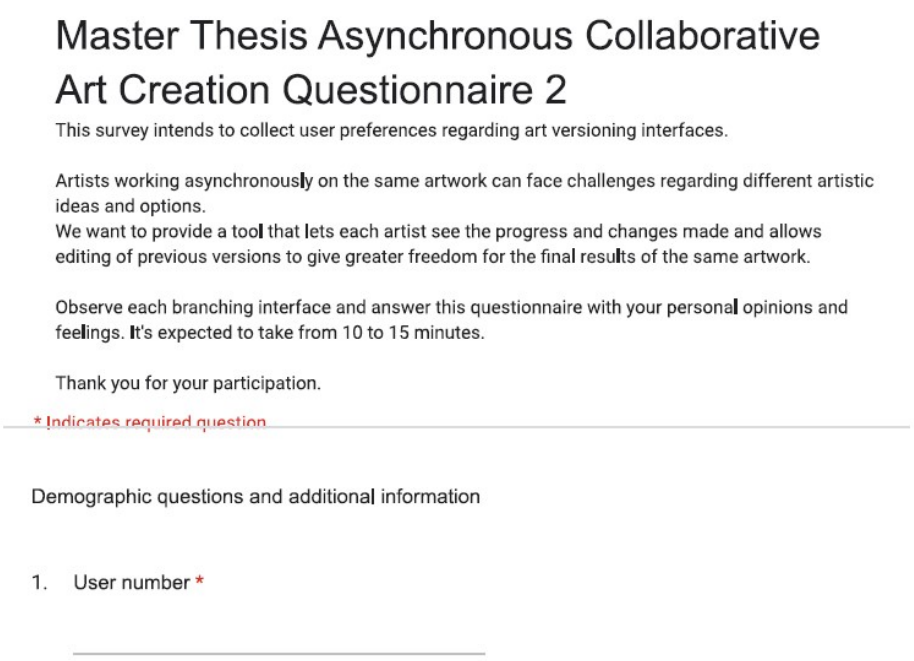
These questions are focused on the experience related to the **virtual reality artwork.** Please answer the following questions while thinking about that experience.

From 1 (completely disagree) to 5 (completely agree) rate this sentences. *

	1	2	3	4	5
By completing the artwork, I was collaborating with other artists.	○	○	○	○	○
I felt close to the original artist of the artwork.	○	○	○	○	○
I understood the objectives given to me.	○	○	○	○	○
I found the objectives easy to complete.	○	○	○	○	○
I was in control of the changes made to the artwork.	○	○	○	○	○
My interactions with the artwork were natural.	○	○	○	○	○
The surrounding environment was ideal for art creation.	○	○	○	○	○
I was immersed in completing the artwork.	○	○	○	○	○
I felt engaged to complete the artwork.	○	○	○	○	○
I had fun while working on the artwork.	○	○	○	○	○
I was confortable during this collaborative work.	○	○	○	○	○
The finished artwork is original.	○	○	○	○	○
The finished artwork is elegant.	○	○	○	○	○
The finished artwork was better with collaboration.	○	○	○	○	○
I imagined different possibilities that I could try in this artwork.	○	○	○	○	○
My experience was consistent with working in real-life artwork.	○	○	○	○	○
I found my movements intuitive in the virtual environment.	○	○	○	○	○
My movements in virtual reality mirrored my actual movements.	○	○	○	○	○
At the end of the experience, I was more proficient with the equipment.	○	○	○	○	○
At the end of the experience, my skills in VR art had increased.	○	○	○	○	○
At the end of the experience, I felt more comfortable with creating VR artworks.	○	○	○	○	○

C

First User Test - Branching Interface Preference Questionnaire



Master Thesis Asynchronous Collaborative Art Creation Questionnaire 2

This survey intends to collect user preferences regarding art versioning interfaces.

Artists working asynchronously on the same artwork can face challenges regarding different artistic ideas and options.
We want to provide a tool that lets each artist see the progress and changes made and allows editing of previous versions to give greater freedom for the final results of the same artwork.

Observe each branching interface and answer this questionnaire with your personal opinions and feelings. It's expected to take from 10 to 15 minutes.

Thank you for your participation.

* Indicates required question

Demographic questions and additional information

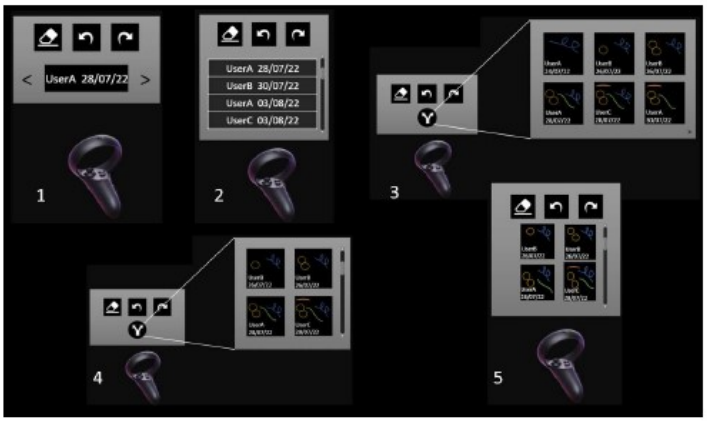
1. User number *

The following set of questions were presented five times, for each interface shown:

2. From 1 (completely disagree) to 5 (completely agree) rate this sentences. *

Mark only one oval per row.

	1	2	3	4	5
This prototype seems easy to learn.	◯	◯	◯	◯	◯
This prototype looks easy to use.	◯	◯	◯	◯	◯
This prototype's interface is clean.	◯	◯	◯	◯	◯
This prototype's interface is structured in an expected way.	◯	◯	◯	◯	◯
This prototype's interface is creative.	◯	◯	◯	◯	◯
This prototype has what the functionality needs.	◯	◯	◯	◯	◯
This prototype is useful.	◯	◯	◯	◯	◯



7. How would you improve one of the features of these prototypes?

8. Was there something unexpected in these prototypes?

9. Do these prototypes seem applicable to you and your artistic expression?

10. Overall, the prototype/s that correspond/s more to the problem presented is/are: *

Check all that apply.

- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5
- [ ] Other: _____

D

Second User Test - Demographic and Immersion Tendencies Questionnaire

To facilitate data analysis, we administered two separate questionnaires, one for each user in the pair. The questionnaire content was identical for both users.

Asynchronous Collaborative Art Creation | Criação de Arte Colaborativa Assíncrona

This consent form is designed to inform you about the user testing process and to seek your permission to participate in a user testing session as part of the Asynchronous Collaborative Art Creation master thesis. Please read the following information carefully before deciding whether you would like to participate.

The purpose of this user test is to evaluate the immersion, ownership and idea exploration of asynchronous artistic collaboration while giving artists a tool that allows the creation of several creative paths for the same artwork.

The user testing will involve your asynchronous collaboration with another artist in 3D painting software and providing feedback on your experience. The user testing will be conducted in person and recorded for review and analysis only for the purpose of this master thesis.

There are no known risks or discomforts associated with this user test.

The user testing is expected to take seven sessions per user.
An initial session of 20 minutes, five daily sessions with 20 minutes each and a final session of 25 minutes.

The information you provide during the user testing will be kept confidential. Your identity will not be disclosed in any reports or publications resulting from the user testing or the master thesis. Your participation in the user testing is voluntary. You may choose not to participate or to stop participating at any time.

If you have any questions about the user testing or the master thesis project, please contact Ana David at ana.claudia.david@tecnico.ulisboa.pt

By proceeding below, you acknowledge that you have understood the information provided in this consent form and agree to participate in the user testing for the purposes of this master thesis.

Este formulário de consentimento foi desenhado para informá-lo sobre o processo deste teste de utilizador e solicitar a sua permissão para participar nas sessões de teste de utilizadores pertencentes à dissertação de mestrado em Criação de Arte Colaborativa Assíncrona. Por favor, leia as seguintes informações cuidadosamente antes de decidir se gostaria de participar.

O objetivo deste teste de utilizadores é avaliar a imersão, a propriedade intelectual e a exploração de ideias da colaboração artística assíncrona, fornecendo aos artistas uma ferramenta que permite a criação de vários caminhos criativos para a mesma obra de arte.

O teste de utilizador envolve a sua colaboração assíncrona com outro utilizador em software de pintura 3D e o feedback sobre a sua experiência com o mesmo. O teste de utilizador será realizado pessoalmente e gravado para revisão e análise, somente com o propósito desta dissertação.

Não há riscos ou desconfortos conhecidos associados a este teste de utilizador.

O teste de utilizador deve levar cerca de sete sessões por utilizador: uma sessão inicial de 20 minutos, cinco sessões diárias de máximo 20 minutos cada e uma sessão final de 25 minutos.

As informações que fornecer durante o teste de utilizador serão mantidas confidenciais. A sua identidade não será revelada em nenhum relatório ou publicação resultante do teste de utilizador ou da dissertação de mestrado. A sua participação no teste de utilizador é voluntária. Pode escolher não participar ou interromper a sua participação a qualquer momento.

Se tiver alguma dúvida sobre o teste de utilizador ou sobre o projeto da dissertação de mestrado, pode entrar em contato com Ana David através de ana.claudia.david@tecnico.ulisboa.pt.

Ao prosseguir abaixo, reconhece que entendeu as informações fornecidas neste formulário de consentimento e concorda em participar no teste de utilizador para o propósito desta dissertação de mestrado.

* Indicates required question

Demographic Survey | Questionário demográfico

This survey intends to collect the demographic data and immersion tendencies of the pairs of users participating in the asynchronous collaborative user study.

It's expected to take about 4 minutes.

Thank you for your participation.

Este questionário tem como objetivo recolher dados demográficos e tendências de imersão dos pares de utilizadores que participam no estudo de colaboração assíncrona.

É esperado que necessite de cerca de 4 minutos.

Obrigada pela sua participação.

1. Pair number | Número de par *

_____

User 1 Demographics | Demografia utilizador 1

2. User 1 Gender | Género utilizador 1 *

Check all that apply.

- [ ] Female
- [ ] Male
- [ ] Non-binary
- [ ] Prefer not to say
- [ ] Other: _____

3. User 1 Age | Idade utilizador 1 *

_____

4. User 1 Occupation | Ocupação utilizador 1 *

_____

5. User 1 Level of experience as an artist | Nível de experiência como artista do utilizador 1 *

Mark only one oval.

Hobby

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Professional Artist

6. User 1 Level of experience with Virtual Reality (VR) | Nível de experiência com realidade virtual (VR) do utilizador 1 *

Mark only one oval.

No experience

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Experienced user

User 1 Immersion tendencies | Tendencias de imersão utilizador 1

7. User 1: Do you ever become so involved in doing something that you lose all track of time? | Utilizador 1: Ficas tão envolvido em fazer alguma coisa que perdes a noção do tempo? *

Mark only one oval.

Never
1
2
3
4
5
Often

8. User 1: Do you ever become so involved in a movie or a videogame that you are not aware of things happening around you? | Utilizador 1: Ficas tão envolvido num filme ou num videojogo que não te apercebes de coisas que estejam a acontecer à tua volta? *

Mark only one oval.

Never
1
2
3
4
5
Often

9. User 1: How good are you at blocking out external distractions when you are involved in something? | Utilizador 1: Quão bom és a bloquear distrações externas quando estás focado em algo? *

Mark only one oval.

Not very good
1
2
3
4
5
Very good

E

Second User Test - Painting Session Satisfaction Questionnaire

Asynchronous Collaborative Art Creation: User Session Satisfaction Survey | Criação de Arte Colaborativa Assíncrona: Questionário de Satisfação da Sessão de Utilizador

This survey intends to measure, for each user test session, the user experience related to the asynchronous collaborative art creation.

Now that you've completed your daily user test session, please answer this questionnaire with your opinions and feelings related to today's session.
It's expected to take about 8 minutes.

Thank you for your participation.

Este questionário pretende medir, para cada sessão de teste de utilizador, a experiência do utilizador relacionada com a criação de arte colaborativa assíncrona.

Agora que você concluiu a sua sessão diária do teste de utilizador, por favor responda a este questionário com as suas opiniões e sentimentos relacionados com a sessão de hoje.
Espera-se que necessite de cerca de 8 minutos.

Obrigada pela sua participação.

* Indicates required question

1. Identification (Group-User) | Identificação (Grupo-Utilizador) *

2. Session number | Número de sessão *

Memory task | Tarefa de memória

To better comprehend the user immersion and the session engagement, these memory tasks evaluate the attention, emotional engagement and commitment of information to memory.

Para melhor compreender a imersão do utilizador e o seu envolvimento na sessão, estas tarefas de memória avaliam a atenção, o envolvimento emocional e a recolha de informações para a memória.

Overall user satisfaction | Satisfação geral do utilizador

Questions associated with the experience of today's session.

Questões associadas à experiência da sessão de hoje.

3. Overall, I am satisfied with my work in this session. | No geral, estou satisfeito com o meu trabalho nesta sessão. *

Mark only one oval.

Strongly disagree

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Strongly agree

4. Overall, I am satisfied with my collaborator's work until this session. | No geral, estou satisfeito com o trabalho do meu colaborador até esta sessão.

Mark only one oval.

	Strongly disagree / Strongly agree
1	◯
2	◯
3	◯
4	◯
5	◯

5. This session was mentally demanding. | Esta sessão foi exigente mentalmente. *

Mark only one oval.

	Strongly disagree / Strongly agree
1	◯
2	◯
3	◯
4	◯
5	◯

6. During this session, I felt frustrated or discouraged. | Durante esta sessão, senti-me frustrado ou desanimado. *

Mark only one oval.

Strongly disagree

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Strongly agree

Branching prototype analysis | Análise do protótipo de ramificação

This section collects the users' rationale behind the utilization of the branches and instances features included in the prototype.

Esta seção recolhe as explicações dos utilizadores por detrás da utilização das ramificações e instâncias do protótipo.

7. If, in this session, you created one or more branches, explain your motivation for it. | Se, nesta sessão, criou uma ou mais ramificações, explique a sua motivação para tal.

8. If, in this session, you created multiple instances, explain your motivation for it. | Se, nesta sessão, criou uma ou mais instâncias, explique a sua motivação para tal.

F

Second User Study - Additional Tables

Table F.1: Table showing the relationship between users' immersion tendency and their success rate in answering memory questions.

User identification	Immersion Tendency (%)	Success Rate in Memory Questions (%)
P1U1	66,67	87,5
P1U2	80,00	75
P2U1	53,33	100
P2U2	46,67	100
P3U1	60,00	100
P3U2	66,67	87,5
P4U1	86,67	100
P4U2	73,33	100

Table F.2: Table with the maximum distance between strokes performed by each user, per painting session.

	Maximum distance between strokes			
User identification	Session 1	Session 2	Session 3	Session 4
P1U1	0,98	1,07	1,56	1,72
P1U2	2,34	1,22	1,89	1,66
P2U1	1,47	0,97	1,20	1,50
P2U2	1,27	1,82	1,11	1,56
P3U1	2,20	1,67	2,00	2,57
P3U2	2,17	2,20	1,76	2,21
P4U1	2,27	2,55	2,33	1,48
P4U2	2,17	1,81	1,94	1,71