Algorithms and software for emotion analysis from wearable sensors and full-immersive experience in VR for CH (I)

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Glossary

Acronym	Definition
GSR	Galvanic Skin Response
SCR	Skin Conductance Response
HR	Heart Rate
HRV	Heart Rate Variability
EEG	Electroencephalogram
BVP	Blood Volume Pulse
HVHA	High Valence, High Arousal
LVLA	Low Valence, Low Arousal
HVLA	High Valence, Low Arousal
HVLA	High Valence, Low Arousal
ST	Skin Temperature
ACC	three-axis ACCeleration
ET	Eye Tracking
LSL	Lab Streaming Layer
VR	Virtual Reality

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Executive Summary

The deliverable presents an affective computing framework developed for emotion recognition in the virtual exhibition of the MuseIT project. It aims to accurately detect users' emotional states as they interact with cultural heritage artefacts in VR, using audio and visual content to evoke emotions. The framework is developed based on data collected through a designed experiment, which forms the foundation for training and validating emotion recognition algorithms. Emotional recognition in the context of a virtual exhibition can significantly enhance the user experience, leading to a deeper engagement with the cultural heritage artefacts and provide valuable insights for exhibition design.

Additionally, the document provides an overview of the production phase of the first edition of the MuseIT virtual museum, delineating the conceptualisation of virtual museum design and the progression from 2D architectural plans to 3D modelling of the virtual space. It includes details about the 3D environment and cultural artefacts displayed in the virtual museum, serving as an experimental space for further research regarding multimodality and multisensory experiences. The production phase aligns with pre-production specifications detailed in previous deliverables (D4.1).

1. Introduction

The affective computing and virtual reality (VR) technologies have opened new opportunities for enhancing user experiences in digital environments (Marín-Morales et al., 2020). With the proliferation of VR applications across various domains, there is a growing need to link these immersive experiences with emotional intelligence. By leveraging these technologies, MuseIT aims to enhance user experiences, foster emotional connections with the exhibits, and provide a more immersive exploration of cultural heritage. Emotion recognition, a crucial component of affective computing, holds immense potential for creating more personalised and engaging interactions within VR environments.

This deliverable presents an affective computing framework developed to facilitate emotion recognition in the virtual exhibition of MuseIT project. Leveraging data collected through a designed experiment, our framework aims to train machine learning algorithms to accurately detect users' emotional states as they engage with cultural heritage artefacts presented in VR. The framework utilises both audio and visual content comprising cultural heritage artefacts to evoke a diverse range of emotions.

Key to the development of the framework is the data collection experiment conducted to curate a comprehensive dataset of emotional responses to cultural heritage artefacts in VR. The resulting dataset forms the foundation for training and validating our emotion recognition algorithms.

''Full-immersive experience in VR'' encapsulates the overview of the production phase of the first edition of the full-immersive MuseIT virtual museum. This includes the virtual museology design plan expounding upon the four exhibition thematic areas. Following that, the document delineates the progression of the virtual museum design, from the 2D architectural plan to the 3D modelling of the exhibition space and of artefacts. Apart from the 3D environment of the MuseIT virtual museum, the deliverable presents the 3D cultural artefacts displayed in the virtual experience. A thorough mention, accompanied by screenshots of the artefacts, has been included in this deliverable. D4.2 focuses on the pivotal components of the development of the virtual museum in the game engine. The production phase aligns with task 4.3 and is based on the pre-production specifications detailed in D4.1.

The Affective Computing Framework described in Section 2 and the full-immersive MuseIT virtual museum presented in Section 3 comprise the two interactive modules that will progress simultaneously within MuseIT. Affective Computing Framework will lead to the development of emotional state recognition algorithms (Machine Learning Algorithms) which will be used for the assessment of the emotional experience and engagement of users in the virtual museum.

2. Affective Computing Framework

2.1. Background

Affective computing is a multidisciplinary field at the intersection of computer science, psychology, and cognitive science that focuses on developing computational systems that can recognize, interpret, process, and respond to human emotions effectively (Picars, 2000). Emotions play a crucial role in human-computer interaction HCI, influencing user experience, decision-making, and overall system effectiveness. Thus, integrating affective capabilities into computational systems has become increasingly important in various domains such as healthcare, education, gaming, virtual reality, and human-robot interaction.

In the past few decades, there has been significant progress in the development of affective computing frameworks and models. Initially, early research mainly focused on basic emotion recognition through facial expressions, speech analysis, and physiological signals. However, exploring multimodal approaches that combine various data sources can lead to achieving more accurate emotion detection and understanding.

An emotional state is a multifaceted physiological condition comprising three fundamental components: a subjective experience, a physiological response, and a behavioural or expressive reaction (Peira et al., 2014). In the field of emotional psychology, two prominent models stand out as primary frameworks for understanding emotional states: the discrete model (Ekman, 1992) and the two-dimensional valence-arousal space model (Russell, 1980).

The discrete model proposes that there are a finite number of distinct emotions, each characterised by unique features and physiological responses. This model categorises emotions into primary or basic categories such as happiness, sadness, anger, fear, disgust, and surprise (**Fig. 2.1**). In contrast, the two-dimensional valence-arousal space model offers a more nuanced approach to understanding emotional states (**Fig. 2.2**). This model, often referred to as the circumplex model of affect, represents emotions along two primary dimensions: valence and arousal (Russell, 1980). Valence refers to the degree of pleasantness or unpleasantness associated with an emotion, while arousal refers to the intensity or level of physiological activation. By plotting emotions within this two-dimensional space, the complexity of emotional experiences can be captured, encompassing both qualitative and quantitative aspects of affective states. The model is widely used in the affective computing research, providing a straightforward and intuitive framework for categorising emotional states. In our study, we utilise the two-dimensional valence-arousal model for understanding and analysing emotional states.

Figure 2.1: The six primary emotions according to Ekman (Shen, 2020).

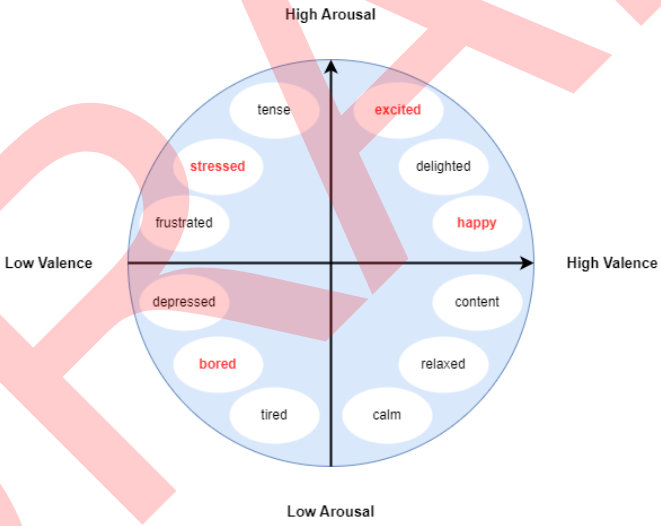

Figure 2.2: The two-dimensional valence-arousal space model.

Existing affective computing frameworks often incorporate machine learning and artificial intelligence techniques to analyse and interpret emotional cues from diverse modalities, including facial expressions, gestures, physiological signals (such as heart rate and skin conductance), and textual data. These frameworks aim not only to recognize discrete emotions but also to capture continuous emotional states and dynamics, such as valence and arousal. This comprehensive approach provides a deeper understanding of affective states.

The creation of an affective computing framework for VR exhibition (ACF-VR) will address key challenges in developing affective computing technologies for multisensory interaction with cultural heritage for the MuseIT project. By assessing users' emotional states and engagement levels, the framework will enable a qualitative evaluation of the emotional experience within the immersive Virtual Reality environment. Through experiments designed to explore users' emotional responses, including physiological signals such as Galvanic Skin Response (GSR), Heart Rate (HR), and Electroencephalogram (EEG), the framework aims to provide an understanding of how individuals respond emotionally to cultural heritage content.

2.2. Physiological signals and emotion

The term "emotion" typically refers to a psychological state that emerges spontaneously, independent of conscious effort (Shu et al., 2018). This is often accompanied by physical and physiological changes that affect various human organs and tissues. These alterations can impact diverse aspects of bodily functioning, including but not limited to the brain, heart, skin, blood circulation, muscles, facial expressions, voice, and more. Emotions are a combination of feelings and physical changes in our bodies that affect how we think, act, and feel overall. Physiological signals in particular are essential for recognizing emotions because of their strong correlation with the body's emotional responses.

Key brain regions involved in emotional processing include the limbic system, which includes structures like the amygdala and hippocampus, responsible for processing emotional memories and assigning emotional significance to stimuli (LeDoux, 1996). The prefrontal cortex also plays a role in regulating emotions by modulating cognitive appraisal and response selection (Rolls, 2019). Multiple studies suggest that emotional states are associated with electrical activity in the central nervous system, detectable using EEG devices (Torres et al., 2020). These signals, providing accurate temporal resolution and directly reflecting neuronal activity, offer reliable insights into emotions. EEG-based Brain-Computer Interface devices, including wearables and headbands, provide a cost-effective and accessible means of capturing EEG signals, fostering extensive research in emotion recognition. Interpretation of EEG data requires sophisticated analysis techniques to eliminate artefacts from eye movements, muscle activity, and environmental noise.

GSR, also known as Skin Conductance Response (SCR), is a physiological measure that reflects the changes in the electrical conductivity of the skin due to sweat gland activity. It's often used as an indicator of emotional arousal and stress levels (Boucsein, 2012; Dawson et al., 2007). When a person experiences an emotional reaction, such as excitement, fear, or anxiety, their sympathetic nervous system becomes activated. This activation leads to increased sweating, which in turn affects the skin's conductivity. GSR sensors detect these changes by measuring the electrical conductance on the skin (Kreibig, 2010). GSR signals can also be affected by non-emotional factors such as physical activity, skin moisture, and environmental conditions.

Emotions are also often associated with variations in heart rate (HR), heart rate variability (HRV), and blood volume pulse (BVP). More specifically, HR, which is the number of times the heart beats per minute, is influenced by the sympathetic and parasympathetic branches of the autonomic nervous system. During emotional arousal, such as excitement or stress, sympathetic activation typically increases HR (Shaffer & Ginsberg, 2017). HRV refers to the variation in the time intervals between successive heartbeats. It is a measure of the flexibility of the autonomic nervous system and reflects

the balance between sympathetic and parasympathetic activity. Higher HRV is generally associated with better emotional regulation and adaptability (Laborde et al., 2019). BVP is a measure of the change in blood volume providing information about how blood flows with each heartbeat. Changes in BVP can reflect emotional arousal and sympathetic nervous system activation (Posada-Quintero & Avila-Ortiz, 2019).

By integrating multiple physiological signals, the limitations of individual modalities can be overcome, and the accuracy and robustness of emotional recognition algorithms can be enhanced. Combining physiological, neural, and peripheral measures allows for the integration of complementary information, enhancing the accuracy of emotion classification.

2.3. Data collection experiment

This section offers an in-depth overview of the emotion-inducing experiment CERTH conducted involving the collection of physiological signal data. This collection will advance the development of emotion recognition algorithms for the MuseIT project. The experiment was approved by the Ethical Committee of CERTH (protocol number: 016041). The subsequent paragraphs provide detailed information on the hardware and software equipment necessary for implementing the study, as well as its setup to ensure proper data acquisition. Additionally, the demographics of the participants, the questionnaires they answered, and the protocol they followed are outlined.

Considering our emphasis on multisensory stimuli inspired by artistic elements, we made a deliberate decision to include both visual and auditory stimuli. In particular, the WikiArt emotions dataset (Mohammad & Kiritchenko, 2018) was chosen for visual stimuli, and the 1000 Songs database (Soleymani et al., 2013) for auditory stimuli.

Visual Stimuli

WikiArt Emotions is a dataset of 4,105 pieces of art (mostly paintings) that has annotations for emotions evoked in the observer. The pieces of art were selected from WikiArt.org's collection which is publicly available (https://www.wikiart.org/), for four Western styles (Renaissance Art, Post-Renaissance Art, Modern Art, and Contemporary Art). The art was annotated via crowdsourcing for one or more of the twenty emotion categories:

- Positive: happiness, gratitude, humility, love, optimism, trust
- Negative: anger, arrogance, disgust, fear, pessimism, regret, sadness, shame
- Other or mixed: agreeableness, anticipation, disagreeableness, surprise, shyness, neutral

Each artwork received annotations from a minimum of 10 workers, ensuring a diverse perspective was captured. The determination of emotion labels was based on the percentage of responses indicating a particular emotion, with thresholds set at 30%, 40%, or 50%. Following the recommendation of the authors, the 40% threshold was selected as the criterion for assigning emotion labels. Furthermore,

our selection process involved identifying artworks that fell into distinct categories of emotions, specifically those exclusively associated with positive sentiments or those exclusively linked with negative sentiments. This ensured that the chosen pieces reflected a clear emotional polarity. In total, 24 pieces of art were selected, 12 positive and 12 negative as depicted in **Figure 2.3** and **Figure 2.4**, respectively.

Figure 2.3: The selected positive-emotion pictures from the WikiArt dataset

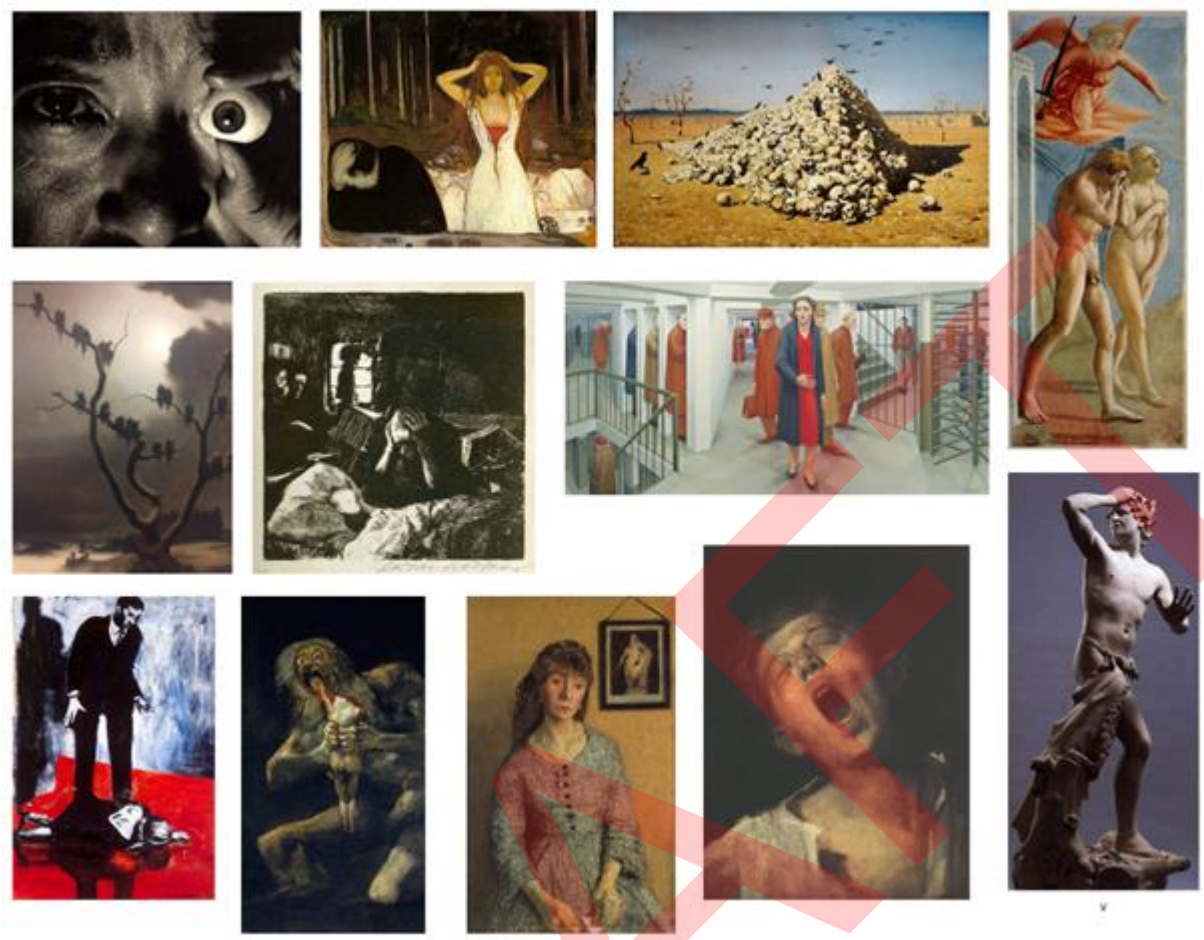

Figure 2.4: The selected negative-emotion pictures from the WikiArt dataset

Audio Stimuli

The 1000 Songs database (Soleymani, 2013) contains songs that have been selected from the Free Music Archive. In particular, 45-second excerpts were extracted from random (uniformly distributed) starting points in a given song. The songs underwent annotation by a large pool of crowdworkers, totaling over 300 annotators, through the platform Amazon Mechanical Turk. The resultant dataset comprises 1000 songs, with each song evaluated by a minimum of 10 individuals. Each song underwent two separate assessments: one for arousal and another for valence, each rated on a nine-point scale ranging from 1 to 9.

To categorise the songs effectively, we established four distinct classes based on their arousal and valence ratings:

- High Valence, High Arousal (HVHA): This class includes songs with an average valence and arousal rating exceeding 4.5/9

- Low Valence, Low Arousal (LVLA): Songs falling into this category exhibit both valence and arousal ratings below 4.5/9

· High Valence, Low Arousal (HVLA): Songs in this class possess a high average valence rating above 4.5/9 but a low average arousal rating below 4.5/9

· Low Valence, High Arousal (LVHA): This category encompasses songs with an average valence rating below 4.5/9 and an average arousal rating above 4.5/9

By employing these criteria, we aimed to create a comprehensive dataset that captures a diverse range of emotional responses evoked by the selected songs. **Table 2.1** provides information on the selected songs from 1000 Songs Database.

Table 2.1 – The songs selected as audio stimuli from the 1000 Songs Database

Song ID	Artist	Song title	Genre	Label
635	Rat City Brass	The Third Man Theme (Live @ KEXP)	Jazz	High Valence, High Arousal
687	The Underscore Orkestra	Balancing Act Chosen Kale Mazel Tov	Jazz	High Valence, High Arousal
756	Plurabelle	Lips	Pop	High Valence, High Arousal
889	The Freak Fandango Orchestra	Requiem for a Fish	Rock	High Valence, High Arousal
232	Advent Chamber Orchestra-Dvorak	Serenade for Strings Op22 in E Major larghetto	Classical	Low Valence, Low Arousal
197	Marcel Pequel	Eight	Classical	Low Valence, Low Arousal
850	Ergo Phizmiz	Strange Things	Pop	Low Valence, Low Arousal
745	Kreng	Maia	Jazz	Low Valence, Low Arousal
245	Advent Chamber Orchestra-Handel	Entrance to the Queen of Sheba for Two Oboes Strings and Continuo allegro	Classical	High Valence, Low Arousal

872	Cranston	Ticking Away	Pop	High Valence, Low Arousal
985	Beach House	Zebra (Live @ KEXP)	Rock	High Valence, Low Arousal
647	Revolution Void	Scattered Knowledge	Jazz	High Valence, Low Arousal
437	Psychadelik Pedestrian	Night Beach	Electronic	Low Valence, High Arousal
726	Cooper-Moore	Trio Take 5	Jazz	Low Valence, High Arousal
173	Andrew Bisset-Cultural Dis	Ease	Classical	Low Valence, High Arousal
568	U Can Unlearn Guitar	The Incredible Infection of Unintended Invection	Folk	Low Valence, High Arousal

2.3.1 Hardware and software

Empatica E4

The Empatica E4 (Empatica, 2024) is a wearable, unobtrusive, and non-invasive device designed for physiological and behavioural monitoring in research. It incorporates multiple sensors to continuously measure various physiological signals, including GSR with a sampling frequency of 4Hz, BVP with a sampling frequency of 64Hz, skin temperature (ST) with a sampling frequency of 4Hz, and three-axis acceleration (ACC) with a sampling frequency of 32Hz, The subject wears the device on the wrist as a clock (**Fig. 2.5**) and is advised to restrict excessive movements to avoid noise in data collection.

Figure 2.5: The Empatica E4 wearable used in this study to record GSR, BVP, ACC, and ST.

Wearable Sensing's DSI 24

Wearable Sensing's DSI 24 (**Fig. 2.6**) is a physiological monitoring system designed for wearable applications. It consists of a lightweight device equipped with 24 channels for connecting dry electrodes, which can be placed directly on the skin without the need for conductive gels or pastes. This feature makes it convenient and comfortable for monitoring physiological signals such as EEG. The brain activity was recorded, with sampling frequency of 300 Hz, through 21 sensors, namely Fp1, Fp2, Fz, F3, F4, F7, F8, Cz, C3, C4, T7/T3, T8/T4, Pz, P3, P4, P7/T5, P8/T6, O1, O2, A1 and A2, placed in positions that correspond to the International 10-20 System. Sensors A1 and A2 were the reference electrodes and were placed on the mastoid bones. Before the experimental procedure, all electrode impedances were kept below 10 kΩ and the EEG signals were inspected to avoid any anomalies.

Figure 2.6: The Wearable Sensing's DSI 24 EEG device employed in the experiments.

Tobii Pro

The Tobii Pro eye-tracking (ET) system (**Fig. 2.7**) is a non-invasive solution for studying visual attention and behaviour. It consists of remote and wearable device designed to capture and analyse eye movement data. The device is attached to a computer screen.

Figure 2.7: The Tobii Pro eye-tracking system.

PsychoPy

PsychoPy (Peirce et al., 2019) is a versatile open-source software package designed for creating experiments in psychology, neuroscience, and related fields. It provides a user-friendly interface for building experiments using a variety of stimuli presentation methods, such as text, images, sounds, and videos. PsychoPy supports both event-driven and time-driven paradigms, allowing researchers to design experiments with precise control over stimulus timing. Its flexibility, combined with Python scripting capabilities, enables the creation of complex experimental designs tailored to their specific needs. PsychoPy also offers built-in tools for data collection and analysis, making it a comprehensive solution for conducting experiments in psychological research. We used PsychoPy for stimulus presentation, control, and synchronisation (**Fig. 2.8**). **Fig. 2.9** and **Fig. 2.10** depict examples of pop-up windows wherein the properties of the stimulus presentation, (such as their duration), and fragments of code (for producing triggers) can be defined.

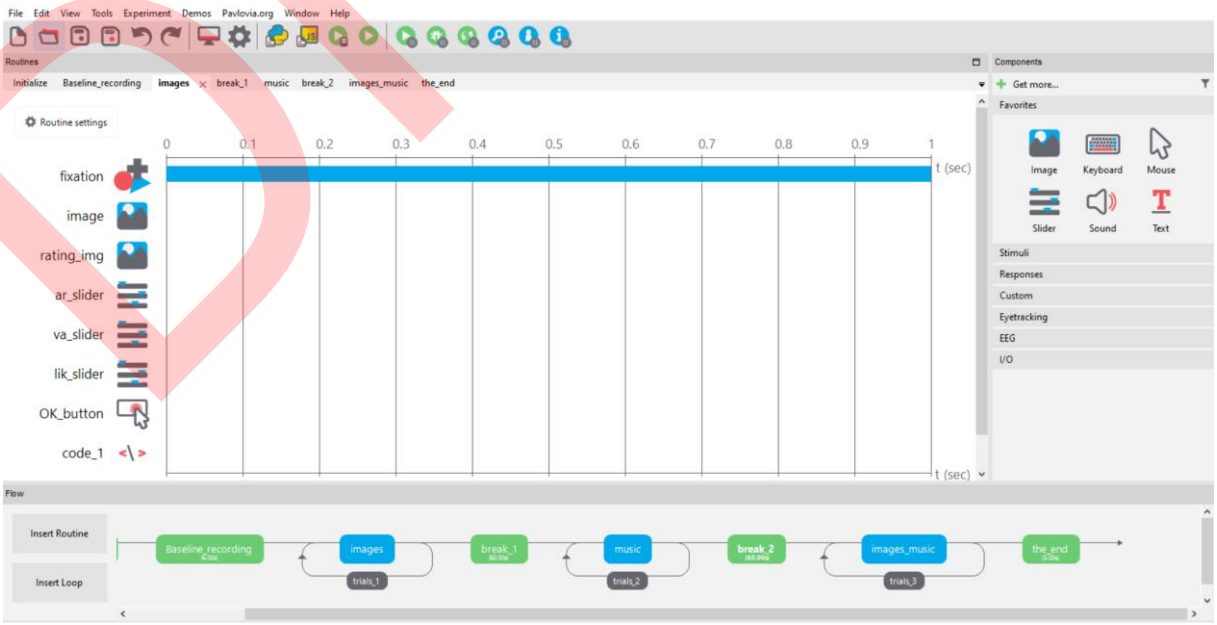

Figure 2.8: The PsychoPy interface

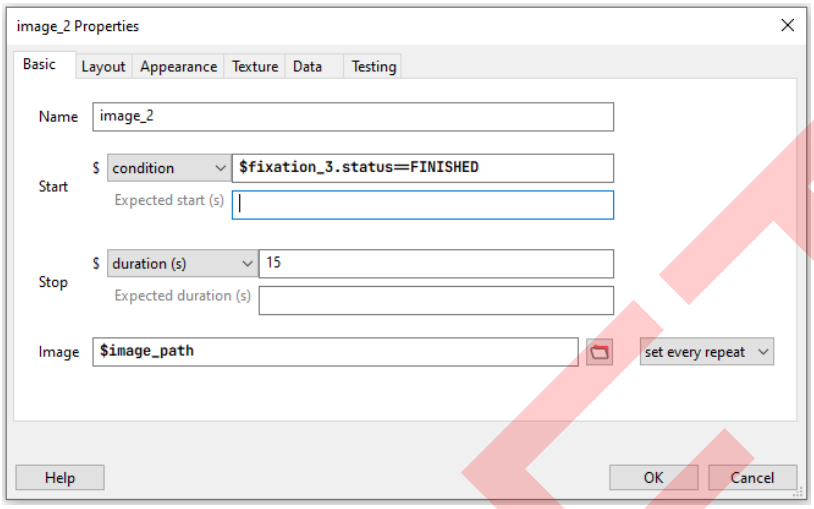

Figure 2.9: Pop-up window for defining properties such as the duration of a stimulus in Psychopy.

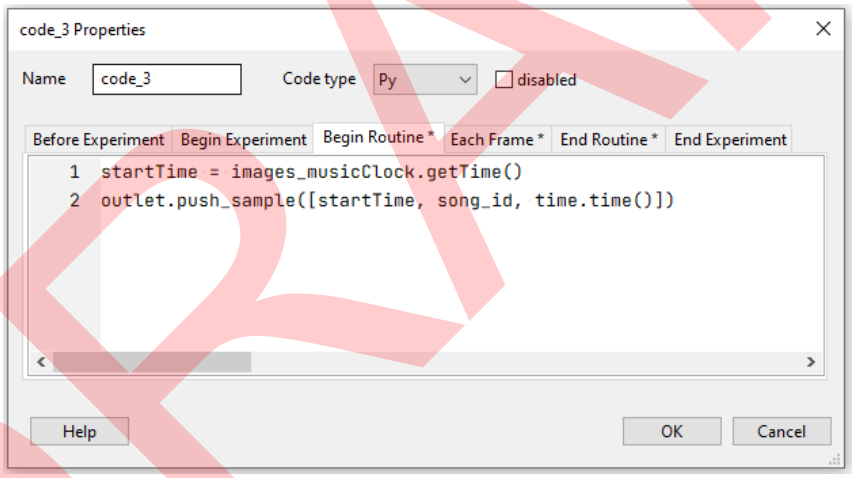

Figure 2.10: Pop-up window for defining properties such as the production of triggers in Psychopy.

Lab Streaming Layer (LSL) and LabRecorder

The Lab Streaming Layer (LSL), is a system designed for the unified collection of time series data during research experiments. It efficiently manages networking, time synchronisation, and near real-time accessibility. The liblsl (Kothe, 2014) library provides Resolvers, which are functions used to identify streams within the lab network. An Outlet is employed to broadcast time series data streams across the lab network, pushing data either sample-by-sample or chunk-by-chunk. Upon subscribing to an Outlet identified via a Resolver, an Inlet establishes a connection to receive time series data.

Additionally, alongside the raw data, stream information is stored and transmitted as XML data. LabRecorder serves as the default recording software accompanying LSL. It facilitates the recording of all streams within the lab network into a single file, ensuring time synchronisation across streams. The file format employed by LabRecorder is XDF, an open general-purpose format developed concurrently with LSL, supporting all LSL stream features. The LabRecorder interface, depicted in **Fig. 2.11**, displays available streams on the lab network in green under the 'Record from Streams' tab. Users can select streams and utilise the 'Start' or 'Stop' buttons to manage stream recording. Furthermore, there is an option to specify the file's name and storage location.

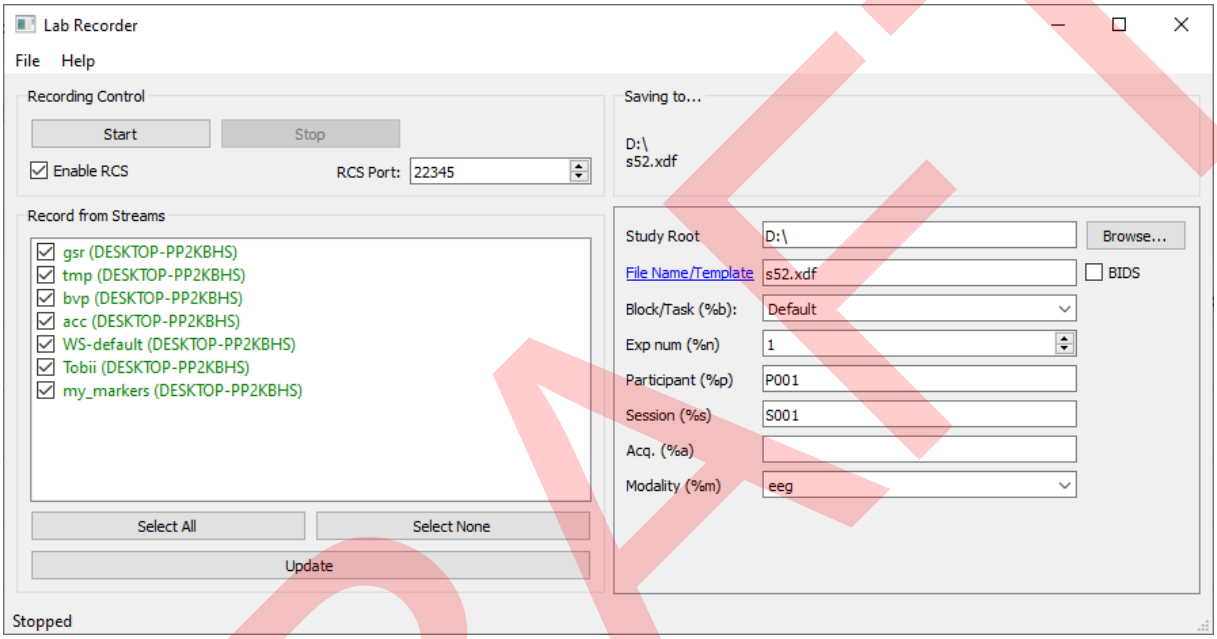

Figure 2.11: The interface of LabRecorder.

Setup and synchronisation

The specified hardware and software components were integrated to configure the experimental setup. Participants were comfortably seated in a chair, with the experimenter assisting in the placement and adjustment of sensors. Participants were instructed to limit their movements to prevent motion artefacts in the signals.

We established 7 streams within LabRecorder (refer to **Fig. 2.11**). The initial 4 streams captured physiological data from the Empatica E4 device (GSR, BVP, ST, ACC), connected to the host PC via Bluetooth. Data streaming and collection were facilitated by a Python script utilising pylsl, the Python interface for the LSL. This script configured StreamInfo from pylsl and established a StreamOutlet to transmit data samples to LSL for recording by LabRecorder. Another stream recorded EEG data from Wearable Sensing's DSI 24, also linked to the same host PC via Bluetooth. Additionally, a stream recorded ET activity through the Tobii Pro device.

The markers stream facilitated offline data synchronisation. In the subsequent section, the experiment's structure comprising multiple trials is further explained. To synchronise signals from each

trial and experimental condition, PsychoPy software was employed to send markers or triggers. Specifically, a Python script initialised a StreamInfo and sent a trigger via the LSL outlet stream upon the start of a trial.

2.3.2 Experimental Protocol

This section details the experimental protocol conducted within the MuseIT project, focusing on the participant involvement, and structured presentation of stimuli to elicit emotional responses. It outlines the setup of the EEG laboratory, participant demographics, questionnaire completion, calibration of physiological sensors, and the structured presentation of visual and auditory stimuli. Additionally, it explains the procedure for obtaining subjective feedback from participants after each trial. It provides insight into the methodology used to gather data for developing emotion recognition algorithms which will enhance the virtual exhibition experience.

Participants' subjective states were assessed using the Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) questionnaire for accessing emotional cues before the experiment and the Big-Five questionnaire (Goldberg, 1992) for personality traits. The full questionnaires, the instructions for participants and the scoring methodology are available in the Annex. Physiological states were monitored through EEG for brain activity, BVP for cardiovascular responses, GSR for arousal levels, and Tobii Eye Tracking for visual attention and interest. These measures collectively provided a comprehensive understanding of participants' emotional and physiological responses during the experiment.

The experiments were carried out in the EEG laboratory at CERTH. Forty-two participants took part in the study (mean age of 30.9 with a standard deviation of 5.53). Twenty-four of them were male and eighteen were female. Before conducting the experiments, participants were required to fill out a demographics questionnaire and provide their consent by signing a form outlining their voluntary participation, as well as ensuring confidentiality, anonymity, and data protection. Following this, the subjects were briefed on the experimental protocol, and the upcoming procedure was thoroughly explained to them. Additionally, participants completed the PANAS questionnaire to assess their current levels of positive and negative affect and their dominant emotional state before the experimental procedure. Finally, the sensors, namely the Empatica E4 wearable and Wearable Sensing's DSI 24, for capturing their physiological responses were positioned and calibrated for accurate data collection. Following the completion of the experimental session, participants were asked to complete the Big-Five questionnaire to determine their personality traits. **Fig. 2.12** depicts two participants while conducting the experiment.

Figure 2.12: Two participants while conducting the experiment

The protocol has been structured into three principal components, each dedicated to presenting specific types of stimuli. These components include one segment for visual stimuli, another for auditory stimuli (music), and a third for audio and visual stimuli simultaneously. Each segment consists of 16 trials, with each trial lasting for a duration of 15 seconds. The presentation order was randomised across subjects and blocks to avoid stimuli-order bias. Before each trial, a screen with a fixation cross is presented to participants for one second. To mitigate potential fatigue and ensure participant comfort, a 60-second break is implemented between each segment. This allows subjects to relax before proceeding to the next segment. Furthermore, before the initiation of the protocol, a 60-second baseline recording of the participant's resting state is recorded for reference and comparison. The pipeline is depicted in **Fig. 2.13**.

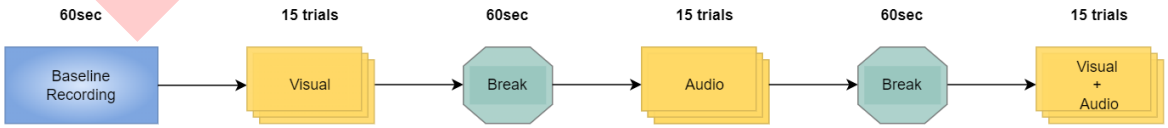

Figure 2.13: The experimental protocol pipeline followed in this study.

For the visual stimuli, participants were presented with a total of 16 artworks, divided into 8 positive and 8 negative images. Regarding the auditory stimuli, subjects listened to 16 music excerpts, categorised into 4 classes: HVLA, LVHA, HVHA, and LVLA. In the combined visual and auditory component, participants experienced both pictures and music stimuli. This block includes 16 sets of stimuli, where each trial comprises both positive-emotion and negative-emotion images along with music excerpts targeting 4 distinct classes (HVLA, LVHA, HVHA, LVLA). The combination of affect-related stimuli for the aforementioned trials in this block can be found in **Table 2.2**.

Table 2.2: The combination of affect-related stimuli for trials in the third block of experiment

Visual	Auditory
2 positive	2 HVLA
2 positive	2 LVHA
2 positive	2 HVHA
2 positive	2 LVLA
2 negative	2 HVLA
2 negative	2 LVHA
2 negative	2 HVHA
2 negative	2 LVLA

After each trial, participants were requested to provide their feedback, an essential step in obtaining the subjective ground truth on their physiological responses. To this end, they rated their arousal level, the valence of their emotions, and their preferences regarding the presented content by clicking on a slider using the mouse (see also **Fig. 2.13**). This method allowed us to obtain scores within the range of 0 to 100 across these three levels. The scores will facilitate the development of personalised, subject-dependent emotion recognition algorithms.

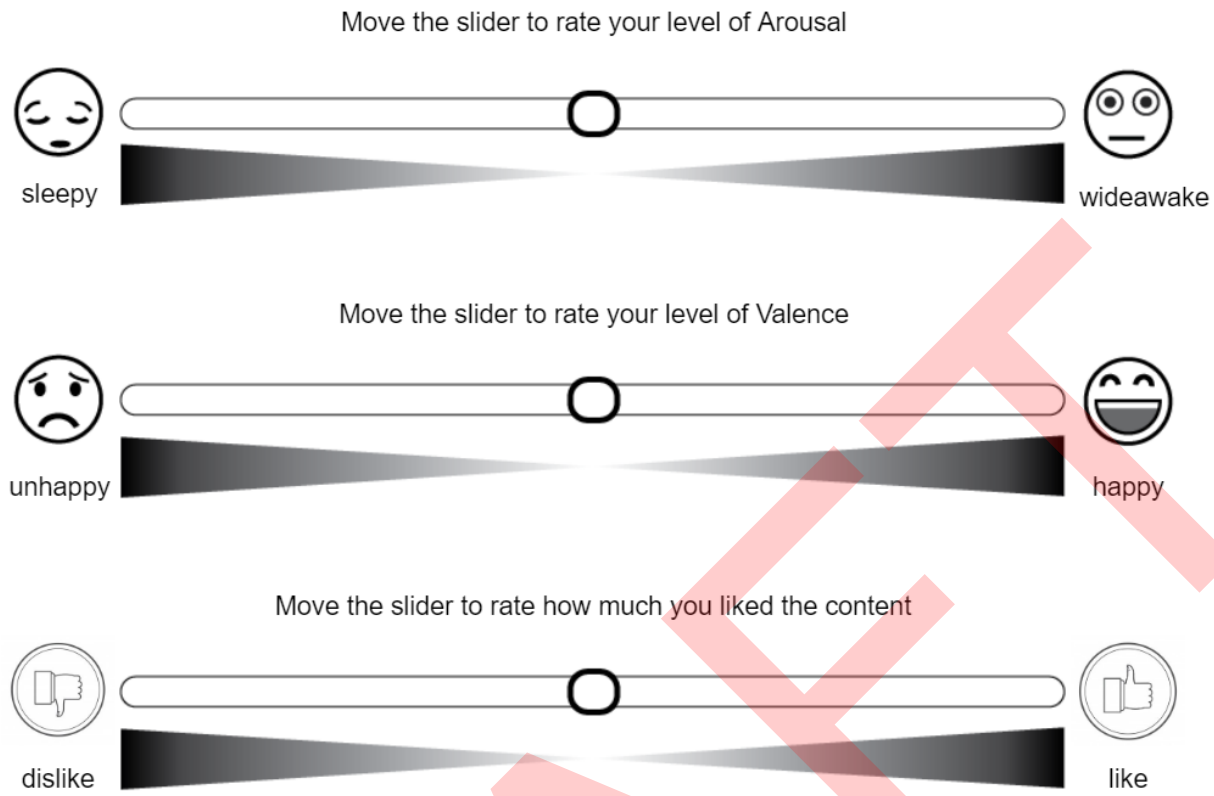

Figure 2.13: The slider provided to subjects after each trial for evaluating their subjective levels of arousal, valence, and liking for the content presented

2.3.3 Preliminary results

This section provides some preliminary results regarding the collected data derived from our experiment. The **Fig. 2.14** depicts the distribution of Big-Five personality traits among the participants. In addition, **Fig. 2.15** depicts the results of PANAS questionnaire, providing information about the affective state participants reported right before conducting the experiment.

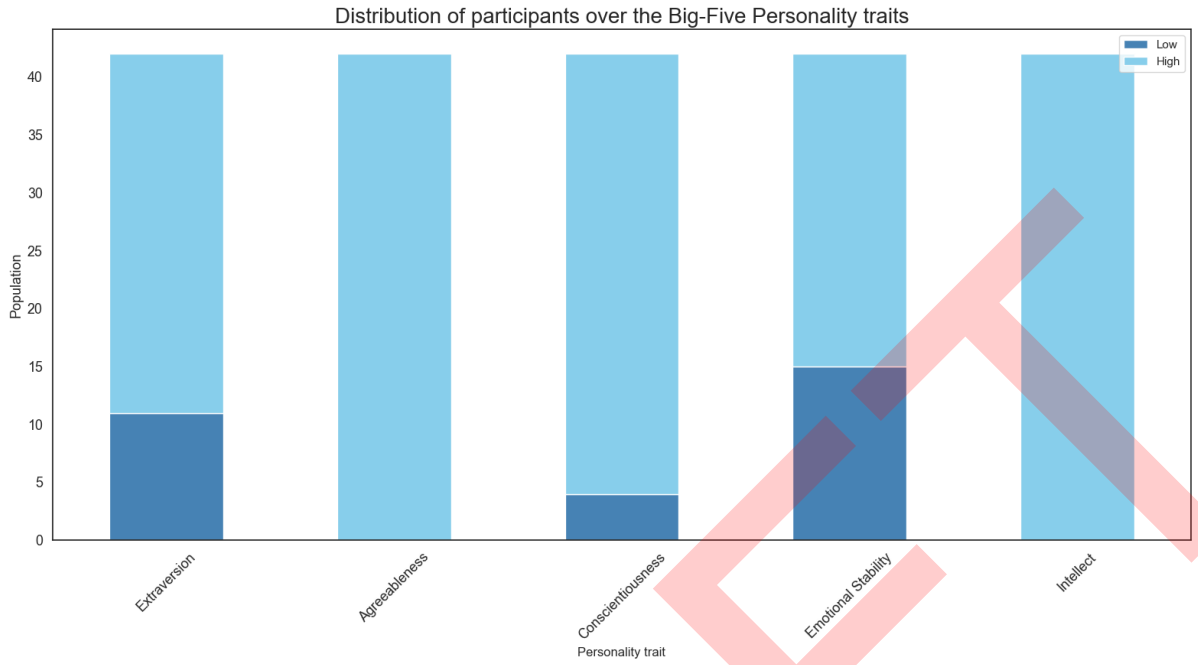

Figure 2.14: The distribution of participants over the Big-Five personality traits.

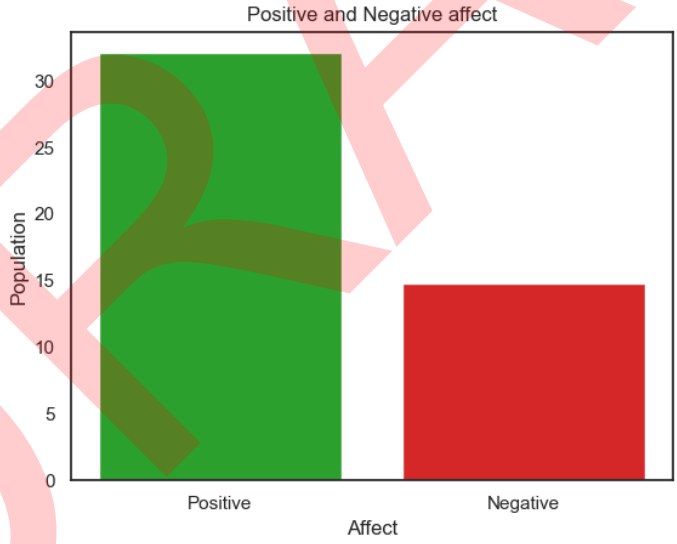

Figure 2.15: The distribution of participants over positive and negative affect as a result of PANAS questionnaire.

The initial phase of the physiological data process involves synchronising the arrays of physiological signals and their corresponding triggers. This synchronisation is essential for ensuring accurate

alignment and correlation among the various data streams and trials. The triggers sent via LSL outlet stream at the start of each trial as explained in the previous section facilitated the precise timing and synchronisation of experimental events.

Following synchronisation, the next step entails inspecting the data to identify any anomalies or irregularities. Subsequently, a thorough pre-processing stage is conducted to clean the data, eliminating any artefacts or noise that may interfere with the analysis. This comprehensive approach aims to establish a reliable foundation for the subsequent analysis and interpretation of the physiological data.

The EEG signals were filtered using a bandpass filter in [0.5, 45] Hz range (Butterworth, 3rd order). This step removes high-frequency noise from various sources, such as muscle activity, powerline interference, or environmental artefacts. In addition, filtering the EEG signals below 45 Hz helps mitigate contamination from eye movement artefacts which are generated in higher frequency bands. Analysis followed by Artefact Subspace Reconstruction (ASR) (Kothe, 2016), which effectively removes a wide range of artefacts from EEG signals by identifying and reconstructing the subspace of the EEG data that is contaminated, while preserving the underlying neural activity. The fully automated online artefact removal method for brain-computer interfacing (FORCe) (Daly, 2014) is combined with ASR to effectively remove transient or large-amplitude artefacts. The raw and pre-processed EEG data of a participant is shown in **Fig. 2.16**. The power spectrum of raw and pre-processed EEG data is depicted in **Fig. 2.17.**

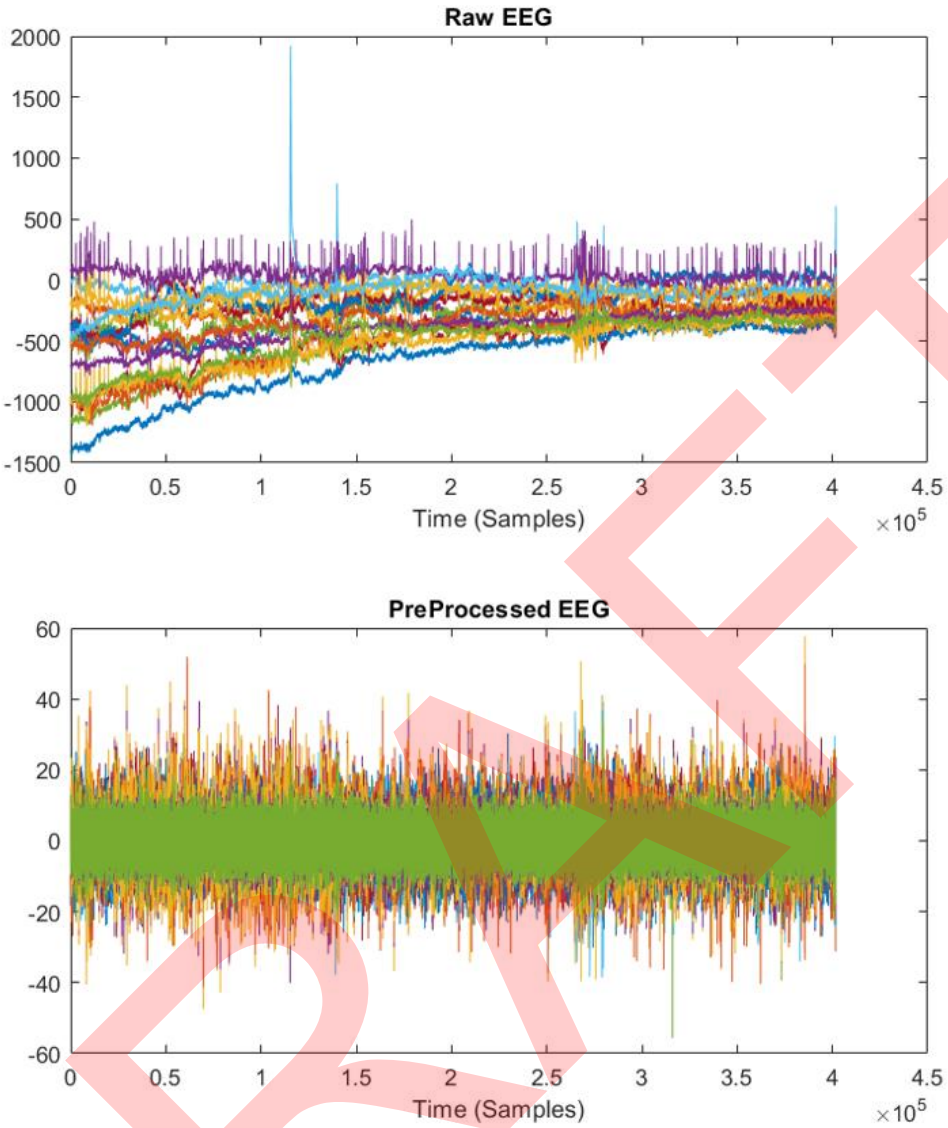

Figure 2.16: The raw (upper panel) and pre-processed EEG signal (lower panel).

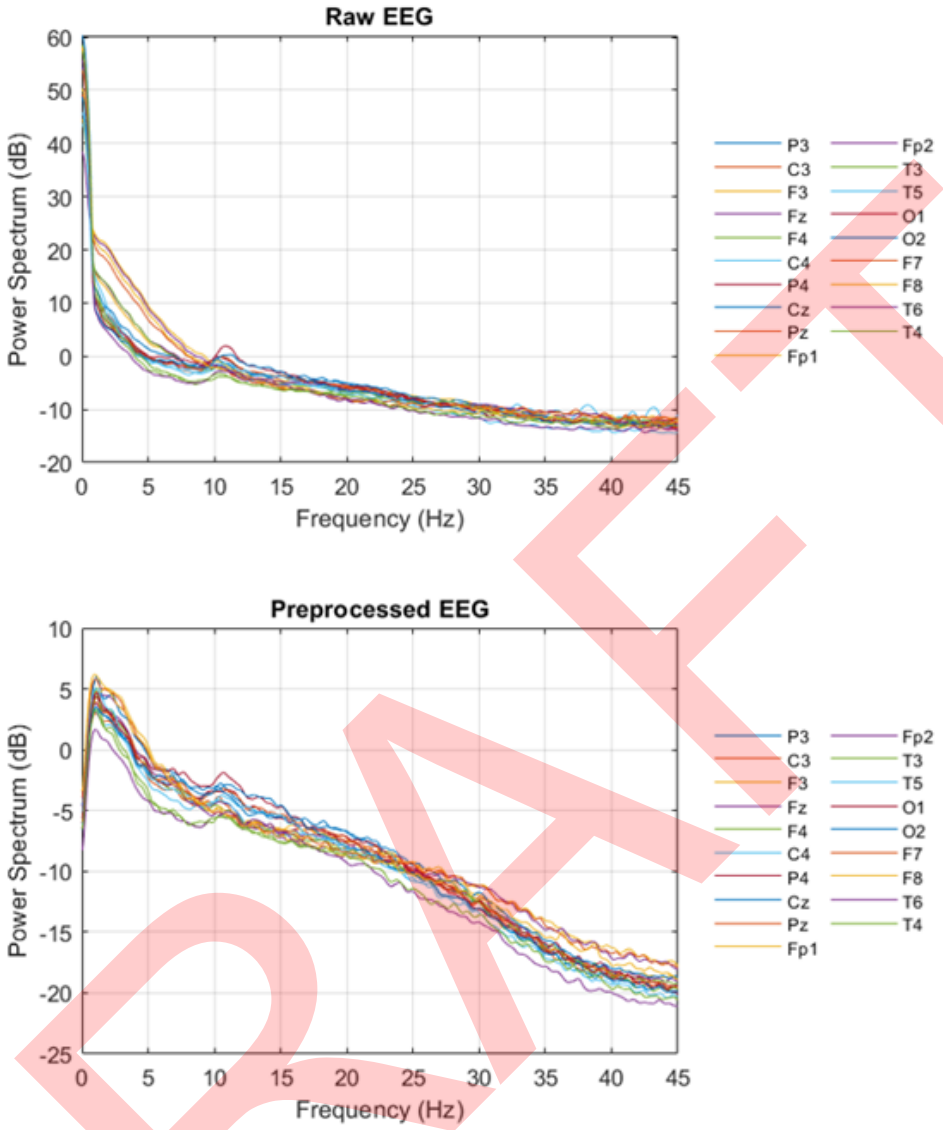

Figure 2.17: The power spectrum of raw (upper panel) and pre-processed EEG signal (lower panel).

The BVP signals were filtered using a bandpass filter in [0.5, 8] Hz range (Butterworth, 3rd order) and the HR was derived using the (Elgendi et al., 2013) method. **Fig. 2.18** depicts the BVP signals and HR of a subject in a given trial.

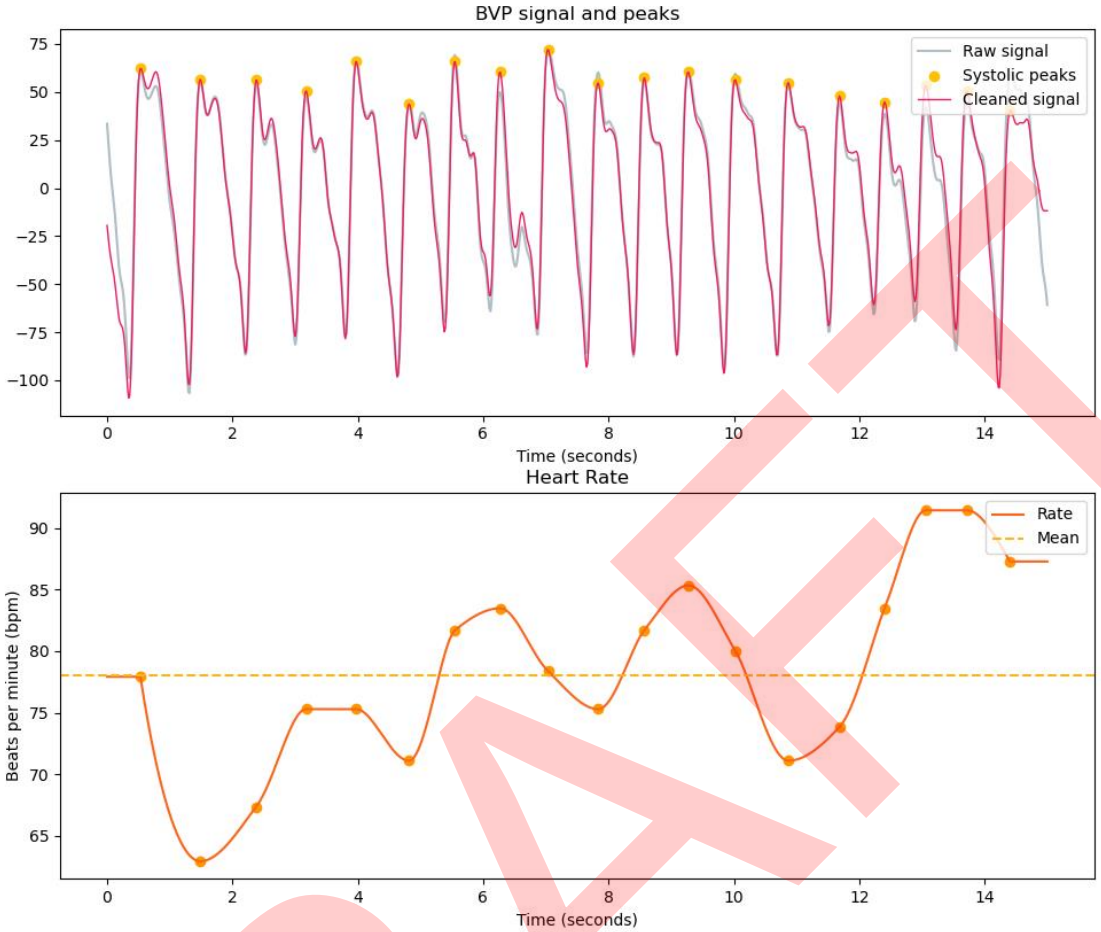

Figure 2.18: BVP signals (top) and HR (bottom) of a subject in a given trial.

The experimental procedure presented in this section comprise the first step towards the development of machine learning algorithms that will detect and recognize emotional states triggered by Cultural Heritage artefacts. These algorithms will be part of the full-immersive experience in VR that is described in the subsequent section. Emotional state detection algorithms will reveal the engagement and emotional reaction of users in the VR environment.

3. Full-immersive experience in VR

This section describes the main development of the first edition for the full-immersive virtual museum of the MuseIT project. It is based on the pre-production phase of its design, as described in deliverable D4.1 and a relevant journal publication (Anastasovitis et al., 2024). According to the technical description of the MuseIT project, the first edition of the virtual museum is a standalone version in VR and it is delivered to other research teams of the MuseIT project for further experiments. In other words, the virtual museum acts as an experimental space for further research regarding multimodality and multisensory (Anastasovitis et al., 2023).

3.1. Virtual museology design

The section 3.1 describes in detail the museological plan of the MuseIT virtual exhibition. In D4.1 "User and system requirements for virtual experiences in cultural heritage" we outlined the basic plan for the virtual exhibition, as it is reflected in the specification of the thematic units and of the artefacts that are on display in each unit. In D.4.1 we also presented the exhibition approach adopted for the development of the exhibition, which can be briefly described as multisensory and multi-layered. This approach provides the users/visitors with the potential of multisensory interaction with the exhibition space as well as the artefacts. The multi-layered approach refers to the perspective of the users' engagement to multiple conceptual and interaction layers of the exhibition.

The concept idea of the MuseIT virtual exhibition was primarily emerged by the available cultural content that was provided by the project's CH partners and data providers, these are namely, the Michael Culture Association (MCA) and the ICCU (Istituto Centrale per il Catalogo Unico). More specifically, through MCA and ICCU, we were provided access to 1. the National Archaeology Museum of Abruzzo collections, 2. the GoTellGo Association collections and, 3. the Library of Archaeology and Art History of Rome collections, whose collections of artefacts are disseminated through the Europeana's web portal[1]. A careful selection of artefacts made by CERTH's multidisciplinary team (referred also in D4.1), composed the MuseIT's exhibition material. The selection criteria were in alignment with the inclusive direction of MuseIT exhibition.

At the core of the MuseIT virtual exhibition lies the multifaceted contexts of a city's history and the ways the artists perceive them and then depict them through their artistic expression. The exhibition narrates the storyline that connects the past and modern artists through the parallel display of artefacts of different chronological periods and with the aim to enlighten the way the same meanings are illustrated differently through time. What is hidden beneath the apparent symbolisms of the artefacts, is the conversion form of perceiving the history, the landscape, the people, the traditions through time.

In the following sections we present the four thematic units that the exhibition plan consists of, referring as well to the museological narrative attached to each unit and collection of artefacts. The users' experience begins at the entrance of the exhibition space, which is described below in Section 3.2. An introductory text (in two parts) welcomes the users/visitors to the exhibition which briefly outlines the purpose and the structure of the exhibition plan. This short introduction provides orientation to the users, making them feel more secure and confident about the experience that follows. Then the users continue to Unit 1. Each artefact is accompanied by its text, a label that describes the basic information about it, e.g. the title of the artefact, material, date, creator, contributor/publisher, dimensions, collection. Not all the information about the artefacts is provided by the data providers, yet in some of them there is information missing mainly about the creator or

[1] https://www.europeana.eu/en

the exact date of its creation. Additionally, there are one to two more levels of information available for those users who want to learn more about the artefacts' historical or artistic context.

3.1.1. Landscape thematic area

The first unit is dedicated to the Roman landscape and displays aspects of depicting it through artistic means. The unit embraces three directions. The first refers to mapmaking and displays four maps (three engravings and one drawing) of Rome of the 16th to the 19th century, which refer to different aspects of depicting the landscape of the city, according to the functionality of the map. More specifically, the four artefacts are (***Table 3.1.1.1***):

Table 3.1.1.1: Label texts of artefacts U1_1 to U1_4.

U1_1 The plan of the village of Rome. Engraving, c.1565, Unknown artist, Rodolfo Amedeo Lanciani (contributor), 280x430 mm, Library of Archeology and Art History of Rome
U1_2 Rome. Engraving,1567, Ferdinand Bertelli, Rodolfo Amedeo Lanciani (contributor), 200x270 mm, Library of Archeology and Art History of Rome
U1_3 Study of the land and the disposition of the sewers in the vicinity of the Palatine, Aventine, Capitoline, Esquiline and Celian mountains. Drawing, 19th c., Giuseppe Valadier, Rodolfo Amedeo Lanciani (contributor), 485 x 462 mm, Library of Archeology and Art History of Rome
U1_4 Antiquae Urbis [Antiquities of the city]. Engraving, 1612-1699, Giacomo Lauro, Rodolfo Amedeo Lanciani (contributor), 245 x 180 mm, Library of Archeology and Art History of Rome

The second direction refers to artistic depictions of the Roman landscape, dating back from the 16th c. to 20th c. This part consists of engravings, drawings and a photograph. It reflects the aesthetic and symbolic impact of the ancient ruins on artistic creation, and the perception of antiquity as an integral part of the evolution of the Roman landscape. This direction consists of six artefacts (***Table 3.1.1.2):***

Table 3.1.1.2: Label texts of artefacts U1_5 to U1_10.

U1_5 Via Circi Maximi. Engraving, 1556, Marco Fabio Calvo, 265x375 mm, Library of Archeology and Art History of Rome
U1_7 Roman Forum, Panorama. Engraving, 1790, Unknown artist, Rodolfo Amedeo Lanciani (contributor), 561x844 mm, Library of Archeology and Art History of Rome
U1_6 View of the Roman Forum from the east. Drawing, 19th c., Unknown artist, Rodolfo Amedeo Lanciani (contributor), 229x378 mm, Library of Archeology and Art History of Rome
U1_8 Colosseum, exterior. Drawing, 1836, Luigi Rossini, Rodolfo Amedeo Lanciani (contributor), 282x425 mm, Library of Archeology and Art History of Rome
U1_9 View of the Colosseum from Palatine Hill. Drawing (watercolour, pen and brown ink), 1780-1781, Francis Towne, Rodolfo Amedeo Lanciani (contributor), 370x535 mm, Library of Archeology and Art History of Rome

U1_10 General view of the central and eastern area of the Roman Forum taken from the via del Campidoglio. Photograph, 20th c., Unknown photographer, Rodolfo Amedeo Lanciani (contributor), 185 x 241 mm, Library of Archeology and Art History of Rome

The third direction relates to examples of artistic approaches of the modern landscape, attributed to street artists, which reflect a more symbolic perception of the city than a realistic representation of it. There are two artworks attached to this direction **(*Table 3.1.1.3*)**:

Table 3.1.1.3: Label texts of artefacts U1_11 to U1_12.

U1_11 Abstract landscape. Mural (Stencils), 2013, Sten & Lex, GoTellGo Cultural Association
U1_12 Soul city. Mural, 2015, Maupal, GoTellGo Cultural Association

In the cases of the additional information about an artefact, this may refer to a description of the composition of a lithograph, or to elements of its historical or artistic context, or even to the location of the artwork. Some indicative examples of the object's multilayered information follow below **(*Tables 3.1.1.4, 3.1.1.5, 3.1.1.6, 3.1.1.7*)**:

Table 3.1.1.4: Example 1 of artefacts' multilayered information.

Level 1: basic information	Level 2: description of the composition	Level 3: reference to its historical context
1.1 The plan of the village of Rome. Engraving, c.1565, Unknown artist, Rodolfo Amedeo Lanciani (contributor), 280x430 mm, Library of Archeology and Art History of Rome	Plan of a part of the city of Rome oriented north down. On the left stretch is the Tiber River, with the inscription "Mensura et canne romane 50" (scale and measuring rod), with a small ladder next to it. Near the river is the Castel Sant'Angelo, above an indication of the Trastevere district. In the center, the S. Spirito hospital and the Vatican basilica are clearly visible	It partially recalls the map of Rome published in: Giulio Ballino, "De' disegni delle più illustri città, et fortezze del mondo...", In Vinegia, appresso Bolognino Zaltieri, 1569. The presumed date of publication can be deduced from the fact that in the plan, the Castel Sant'Angelo appears with the final layout of Pius IV, who died in 1565

Table 3.1.1.5: Example 2 of artefacts' multilayered information.

Level 1: basic information	Level 2: description of the composition	Level 3: reference to its creator
1. 8 Colosseum, exterior. Drawing, 1836, Luigi Rossini, Rodolfo Amedeo Lanciani (contributor), 282x425 mm, Library of Archeology and Art History of Rome	The view of the outside of the Colosseum is animated by numerous characters, and the church of Ss. Giovanni e Paolo can be seen in the background.	Luigi Rossini (1790- 1857) was an Italian artist, known for his etchings of Roman architecture

Table 3.1.1.6: Example 3 of artefacts' multilayered information.

Level 1: Basic information	Level 2: description, reference to its creator and its original context	Level 3: description of its elements
3.3 Pope San Pietro Celestino. Sculpture, late 15th c. Saturnino Gatti (attributed), 110cm, MUNDA-National Museum of Abruzzo, L'Aquila	The work is made of limestone. It is attributable to the same artist who carved the Madonna and Child exhibited in the MUNDA-National Museum of Abruzzo in L'Aquila (Abruzzo, Italy) and also coming from the facade of the Church of Santa Maria di Collemaggio in the same city. The sculpture represents Pope San Pietro Celestino standing in a frontal position, holding the model of the city of L'Aquila with his left hand	Pope San Pietro Celestino wears the papal headdress and a large cloak framed with floral motifs, which covers him, below a pleated dress held at the waist.*The statue lacks the right arm

Table 3.1.1.7: Example 4 of artefacts' multilayered information.

Level 1: basic information	Level 2: reference to its location
4.18 Vittorio De Sica - Umberto D. Poster Street art, 2009, Zilda, GoTellGo Cultural Association	The street artwork is located in Rione Monti, in Via Ciancaloni

Except for a very few cases, in which the name of the creator is given with a very short description of his identity, e.g. in the artefact 3.8, level 3 includes the information "Benedict Joseph Labre (1748-1783) was as a French Franciscan tertiary, and Catholic saint. Francesco Barbazza was an Italian engraver, active in the late 18th c.", all the information about the objects, as displayed in the exhibition's labels, is provided by the data providers through the Europeana platform.

Having completed the route in Unit 1, the user exits the space of Unit 1 and enters a central space where three separate exhibition rooms are structured around it. This arrangement of the three units in the exhibition plan reflects that the units are of equal importance, they symbolise three different but equal aspects of a city's history.

3.1.2. History thematic area

The second thematic unit is a tribute to Rome's history. Through a collection of seven engravings, this unit displays the military side of Roman past and the ways that the defenders emperors of the Roman empire were honoured for their services. The seven engravings originate from collective works that narrate the triumphal victories of the emperors Julius Caesar and Trajan. The seven engravings are as follows **(*Table 3.1.2.1*)**:

Table 3.1.2.1: Label texts of artefacts U2_1 to U2_7.

U2_1 "Hostilia arma, cassides, clypei, peltae, loricae, arcvs, pharetrae barbarorvm trophaea. Item avrvm signatvm, et praeda victarvm gentivm, et regvm. Andreas Mantinea pinxit Mantuae" * Triumph scene from the work "C. Iulii Caesaris dictatoris triumphi de Gallia, Aegypto, Ponto, Africa, Hispania, quinquies eodem mense triumphantis; omnium, qui unquam fuere, Ducum, Regum Bellica virtute praestantissimi ab Andrea andrea Mantinea eximio, atque insigni Pictori Mantuae" * Rome, Domenico de Rossi, 1692". Engraving, 1692, Robert van Audenaerde after Andrea Mantegna's

paintings, workshop of Domenico de Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 390x410 mm circa, Library of Archeology and Art History of Rome
U2_2 "Tabula marmorea, pugnae Dacicae: ex diruto Traiani; ut putatur; arcu; in Constantini cognomento Magni; qua Spectat Aventinum; ornatus caussa; Romae translata. Antonii Lafrerii Seguani formis Romae 1553 " * "Marble picture of the Battle of Dacia; from the arch of Trajan, demolished, so it is believed, in the name of Constantine the Great; from which one observes the Aventine Hill; for the sake of ornamentation; transported to Rome" * From the work "C. Huelsen, Das Speculum Romanae Magnificentiae des Antonio Lafreri, in Collectanea variae Riferinae Leoni S. Olschki..., Monachii 1921, n. 16a;". Engraving, 1553, Nicolas Beatrizet, Antonio Lafrery (Rome, printer), Rodolfo Amedeo Lanciani (contributor), 272x380 mm, Library of Archeology and Art History of Rome
U2_3 TRIUMPHI, uti L. Paulus de rege Macedonum Perse capto, P. Africanus Aemilianus de Carthagenensibus excisis, C.N. Pompeius Magnus ex oriente, Julius Augustus, Vespasianus, Trajanus et alii imperatores Romani, triumpharunt. Ex antiquissimis lapidum, nummorum et librorum monumentis accuratissima descriptio {BVE0818734} " * "The most extensive and most decorated triumph, as L. Paulus continued to capture the king of the Macedonians, P. Africanus Aemilianus cut off from the Carthaginians. BC Pompey the Great from the East, Julius Augustus, Vespasian, Trajan, and other Roman emperors triumphed. A detailed description of the most ancient records of stones, coins and books {BVE0818734}. Engraving, 1648-1677, Giovanni Giacomo Rossi (printer), 156x360 mm, Library of Archeology and Art History of Rome
U2_4 "Vnus ex transfugis e' Dacia ad occidentum Traianum in Missam profectus, ab suspicionem captus, Imperatori defertur, cui Decebali patefacit insidias. Dion ex'phil" from the work "Icones et segmenta illvstriuvm e marmore tabvlarvm qvae Romae adhvc extant a Francisco Perrier, delineata incisa et ad antiqvam formam lapideis exemplaribvs passim collapsis restitvta" (Taf28). Engraving, 1638-1660, Perrier François, Rodolfo Amedeo Lanciani (contributor), 303x220 mm, Library of Archeology and Art History of Rome
U2_5 "Traianus Pont. Max. habitu pateram tenens ante accensam Tripodem celebrat suo oue taurilia in uictimas coesurus Taurum Joui...Matteo Piccioni Fecit". From the series "Low ancient reliefs in Constantine's arc, and in Campidoglio". Engraving, 1655, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 278x205 mm, Library of Archeology and Art History of Rome
U2_6 "Militum Praefectus Tribunosq. e suggestu Traianus alloquitur... M.° Piccioni fecit" At the right bottom "ex Arcu Costantini". Engraving, 1655, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 278x204 mm, Library of Archeology and Art History of Rome

U2_7 Trajan returned to Rome and promising peace to the ambassadors of supplicant barbarians. * "M.° Piccioni fecit." At the right bottom, "ex Arcu Costantini". Engraving, 1650, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 280x200 mm, Library of Archeology and Art History of Rome

This unit is completed by two more artworks, two street art depictions of fighters as they are conceived by modern artists. These fighters are not identified, they do not represent specific historical figures and the compositions do not narrate specific aspects of their military lives, nor do they represent scenes of triumph and honour. In both these two compositions the fighters are in array, they look the enemy directly in the eyes, ready to take action and combat them. The fighters represent an archetypal type of fighter, which has lost his personal identity, has no distinct characteristics as a personality, rather he is one among many, committed to sacrifice himself for defending the values he is fighting for. In the exhibition space, the two street art compositions are discreetly separated from the engravings. Yet, the user/visitor of the virtual exhibition can unconsciously make the conceptual connections among the two artistic approaches, the past and the modern. The two street artworks are (***Table 3.1.2.2***):

Table 3.1.2.2: Label texts of artefacts U2_8 to U2_9.

U2_8 Warriors. Mural, 2007, Unknown artist, GoTellGo Cultural Association
U2_9 The last battle (L'ultima battaglia). Mural, 2013, Stephanie Fabrizi, GoTellGo Cultural Association

The user exits Unit 2 and continues to the left side at Unit 3 or across the hall at Unit 4.

3.1.3. Religion thematic area

The third thematic unit is dedicated to religion, as an element of collective identity and common practice. There are eleven artefacts exhibited in Unit 3 basically according to the chronological order of their content. More explicitly, when entering the exhibition space of Unit 3, the user/visitor sees a group of three artefacts, resembling the ancient religion, a sculpture of Hercules, an engraving of Diana and a roman sculpture of a man who probably represents a priest belonging to an ancient collegium in charge of the cult of Magna Mater, Ceres, and Apollo. These three artefacts, although their creation dates to different periods, illustrate the ancient Roman religion. The three artefacts are (***Table 3.1.3.1***):

Table 3.1.3.1: Label texts of artefacts U3_9 to U3_10.

U3_9 Resting Hercules, sculpture, 3rd c. BC, 39cm, National Archaeological Museum of Abruzzo Villa Frigerj
U3_11 Diana, Engraving, 17th c., Unknown artist, 270x186 mm, Library of Archeology and Art History of Rome
U3_10 Roman portrait of an old man, Sculpture, 146-31 BC., 32cm, MUNDA-National Museum of Abruzzo, L'Aquila

The second part of the Unit 3, and also the more extensive one, consists of a collection of sculptures from the 13th to 16th c., depicting the Madonna, the Holy Family and Saints of the Catholic church. The user witnesses the transformation in approaching the sanctity artistically, from the late antiquity to the mediaeval period, which profoundly resembles the spiritual diversities between the ancient Greek-Roman religion and Christianity. Contrary to the vividness and the symbolic naturalism of the ancient gods, the holy religious figures have lost their human substance, their vertical, elegant forms radiate humility, tenderness and respect. This collection of the 3D artworks belongs to the National

Museum of Abruzzo, but their original place was inside churches of the area of the L' Aquila, in the region of Abruzzo. Because of their original context, as parts of churches' decoration, they are mainly made to be seen from their front side and their backside was probably not visible. The second part of Unit 3 also includes an engraving depicting Benedict Joseph Labre in front of the Colosseum. The artworks exhibited in this part are (***Table 3.1.3.2***):

Table 3.1.3.2: Label texts of artefacts U3_1 to U3_8.

U3_1 Madonna delle Concanelle. Sculpture, 1262, Magister Machilonus and son, MUNDA-National Museum of Abruzzo, L'Aquila
U3_2 Enthroned Madonna with the Child. Sculpture, c.1340, Master of Santa Caterina Gualino, 116cm, MUNDA-National Museum of Abruzzo, L'Aquila
U3_3 Pope San Pietro Celestino. Sculpture, late 15th c. Saturnino Gatti (attributed), 110cm, MUNDA-National Museum of Abruzzo, L'Aquila
U3_4 Madonna with the Child. Sculpture, 1506, Saturnino Gatti, 116cm, MUNDA-National Museum of Abruzzo, L'Aquila
U3_5 Saint Athony the Abbot. Sculpture, 1512, Saturnino Gatti, 140cm, MUNDA-National Museum of Abruzzo, L'Aquila
U3_6 Holy Family Group. Sculpture, late 15th - early 16th c., Saturnino Gatti, 100-110cm., MUNDA-National Museum of Abruzzo, L'Aquila
U3_8 Imago Servi Dei Benedicti Joseph Labre / Nic.us La Piccola inv. et pinx., Franc. Barbazza sculp. Engraving, 1788, 400x265 mm, Francesco Barbazza, Rodolfo Amedeo Lanciani (contributor), Niccolò Lapiccola (contributor), Library of Archeology and Art History of Rome

The route in Unit 3 is completed with a contemporary depiction of Christ in a street artwork that comes from the streets of the historical centre of Rome (***Table 3.1.3.3***):

Table 3.1.3.3: Label texts of artefact U3_7.

U3_7 Migrant 4 life. Poster street art. 2018, Qwerty, GoTellGo Cultural Association

The user exits Unit 3 and continues to the last unit of the virtual exhibition, the Unit 4.

3.1.4. People thematic area

The fourth and last exhibition unit is a narrative about people and the way they perceive their role in history. Unit 4 is a tribute to memory making and memory keeping, through a collection of artefacts dating back from the 7th c. BC to modern times. The first group of artefacts consists of a collection of funerary sculptures from L' Aquila of the region of Abruzzo. Funerary sculptures are monuments created to honour and remember the deceased, commonly found over the burial sites. They can take various forms and serve multiple purposes, including providing a place for mourning, commemorating the life of the deceased, and symbolising cultural or religious beliefs about death and the afterlife. This collection of monumental sculptures from the ancient cemeteries of Abruzzo is of high artistic and archaeological value. Among them stands out the 2 metres high statue of the Warrior of Capestrano of the 6th c.BC, one of the most significant artworks of Italian art. The collection is permanently exhibited in the Archaeological Museum of Abruzzo and it consists of the following seven artefacts (***Table 3.1.4.1***):

Table 3.1.4.1 : Label texts of artefacts U4_1 to U4_7.

U4_1 Stele de Guardiagrele. Funerary sculpture, 7th c. BC, 80 cm, MUNDA-National Museum of Abruzzo, L'Aquila
U4_2 Torso di Adessa. Funerary sculpture, 7th c. BC, 80 cm, MUNDA-National Museum of Abruzzo, L'Aquila
U4_3 Dama di Capestrano. Funerary sculpture, 6th c. BC, 30 cm, MUNDA-National Museum of Abruzzo, L'Aquila
U4_4 Warrior di Capestrano. Funerary sculpture, 6th c. BC, 209 cm, MUNDA-National Museum of Abruzzo, L'Aquila
U4_5 Torso di Rapino. Funerary sculpture, 6th c. BC, MUNDA-National Museum of Abruzzo, L'Aquila
U4_6 Head di Manopello. Sculpture, 6th c.-5th c. BC, 327mm, MUNDA-National Museum of Abruzzo, L'Aquila
U4_7 Stele of Penna Sant' Andrea 1. Funerary sculpture, 5th - 4th c. BC, 218 cm, MUNDA-National Museum of Abruzzo, L'Aquila

The route in the fourth unit continues with the second group of artefacts, a collection of four engravings dating to the 17th and 18th c. The four engravings, depicting different aspects of people honouring the past and their ancestors, are (***Table 3.1.4.2***):

Table 3.1.4.2 : Label texts of artefacts U4_8 to U4_11.

U4_8 Depiction of the twins Castor and Pollux and Concordia. Engraving, 17th c., 272 x 205mm, Library of Archeology and Art History of Rome
U4_9 "Caesar avreo cvrrv insignis ad Capitolivm trivnphans incedit retro victoria eivs capiti lavream imponit praeevnte celebra titvlo Veni Vidi Vici", Triumph scene from the work "C. Iulii Caesaris dictatoris triumphi de Gallia, Aegypto, Ponto, Africa, Hispania, quinquies eodem mense triumphantis; omnium, qui unquam fuere, Ducum, Regum Bellica virtute praestantissimi ab andrea Mantinea eximio, atque insigni Pictori Mantuae" * Rome, Domenico de Rossi, 1692". Engraving, 1692, Robert van Audenaerde after Andrea Mantegna's paintings, workshop of Domenico de Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 385x415mm, Library of Archeology and Art History of Rome
U4_10 "[Simolacri ex arcu Costantini] Ill:mo cul...] Pio di Sau.ia [...] Simolacri più veri, che quelli delli antichi Suoi fasti, consacro questo uolume a V. S. Ill.ma ... Mattheo Piccioni / Matheius Piccionius Inventor fecit." Engraving, 1650, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 275x192mm, Library of Archeology and Art History of Rome
U4_11 Inscription used by the architect to make the period of the main restorations visible in the underground arena of the Flavian amphitheatre. Engraving, 18th c., 290x230mm, Library of Archeology and Art History of Rome

The third group of artefacts of Unit 4 consists of a collection of twelve street artworks, depicting the modern perception of the past, aspects of honouring the people of the present and the ideas that shape the character of modern cities. Street art is a form of art open to the public, meant to be widely viewed, appreciated and criticised, thus it may be a means to express shared feelings, and a way to

illustrate the collective memory and identity of a city. Among the artworks of the street art collection exhibited in Unit 4 there are four works depicting major personalities of Italian cinematography (Anna Magiani, Sergio and Franco Citti, Mario Monicelli and Pier Paolo Pasolini) entitled as “Melting Icons”, all created on the occasion of a campaign for the reopening of the Ex Cinema Impero in Via di Acqua Bullicante 121, Rome. More specifically, the twelve artworks are the following (***Table 3.1.4.3***):

Table 3.1.4.3 : Label texts of artefacts U4_12 to U4_23.

U4_12 Gorgeous mother of the Resistance feed me your essence. Poster Street Art, 2015, Ex-voto, GoTellGo Cultural Association
U4_13 Garibaldi. Poster Street Art, 2011, GoTellGo Cultural Association
U4_14 Our lady of football. Poster Street Art, 2014, Ex-voto, GoTellGo Cultural Association
U4_15 Maria Vergine Augusta.Poster Street Art, 21st c., Ex-voto, GoTellGo Cultural Association
U4_16 Male portrait, Mural, 2008, C215, GoTellGo Cultural Association
U4_17 Tribute to the Gospel according to Matthew by Pasolini. Mural, 2013, Mr Klevra, GoTellGo Cultural Association
U4_18 Vittorio De Sica - Umberto D. Poster Street art, 2009, Zilda, GoTellGo Cultural Association
U4_19 Toto. Poster Street art, 2009, Zilda, GoTellGo Cultural Association
U4_20 Melting Icons: Anna Magnani. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association
U4_21 Melting Icons: Sergio and Franco Citti. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association
U4_22 Melting Icons: Mario Monicelli. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association
U4_23 Melting Icons: Pier Paolo Pasolini. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association

3.2. Virtual museum design

This subsection outlines the design process of the first edition of the full-immersive virtual museum, step by step. The concept of the space design of the virtual cultural experience has been expounded in Deliverable 4.1 in Section 5.2, “The space design of the MuseIT virtual exhibition. The need to define and comprehend the shapes and scale of the spaces in the architectural layout was what spurred the design of the architectural plan and some sections of the virtual exhibition (***Fig. 3.2.1, Fig. 3.2.2***). *AutoCAD* by Autodesk is the software that was used, as it is a useful tool for architectural design (Autodesk, 2024). Thus, the disciplinary team of CERTH designed a space with four main exhibition units based on the museological specifications of the D4.1.

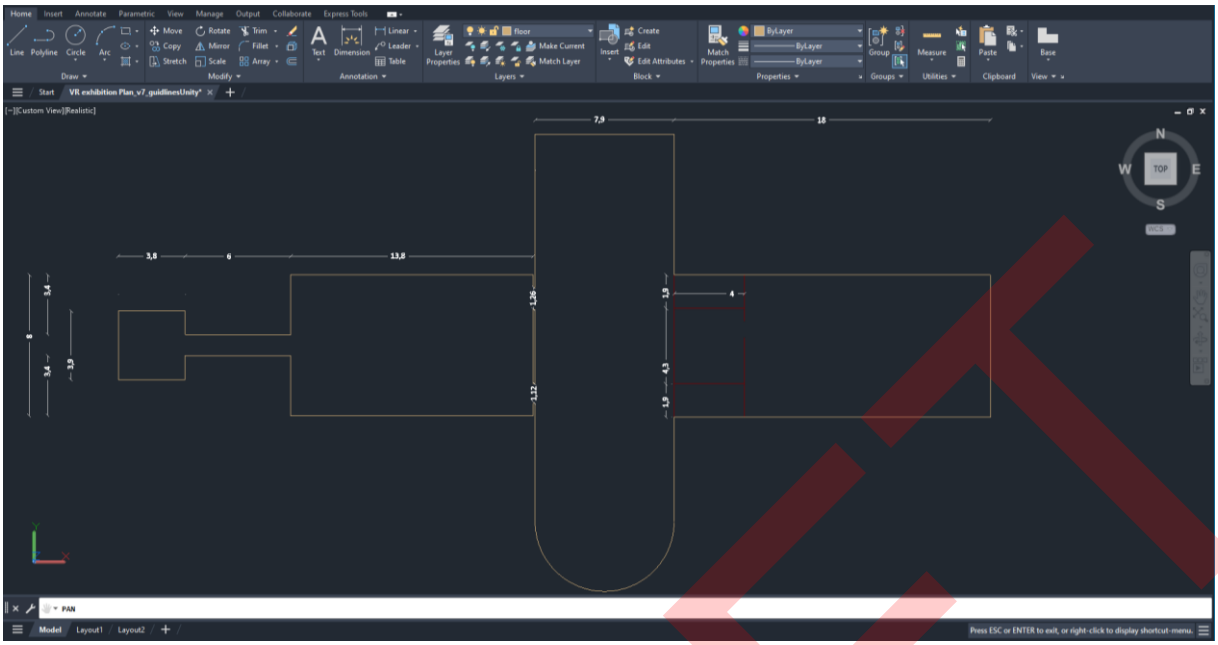

Figure 3.2.1: The architectural plan of the MuseIT virtual exhibition in *AutoCAD*.

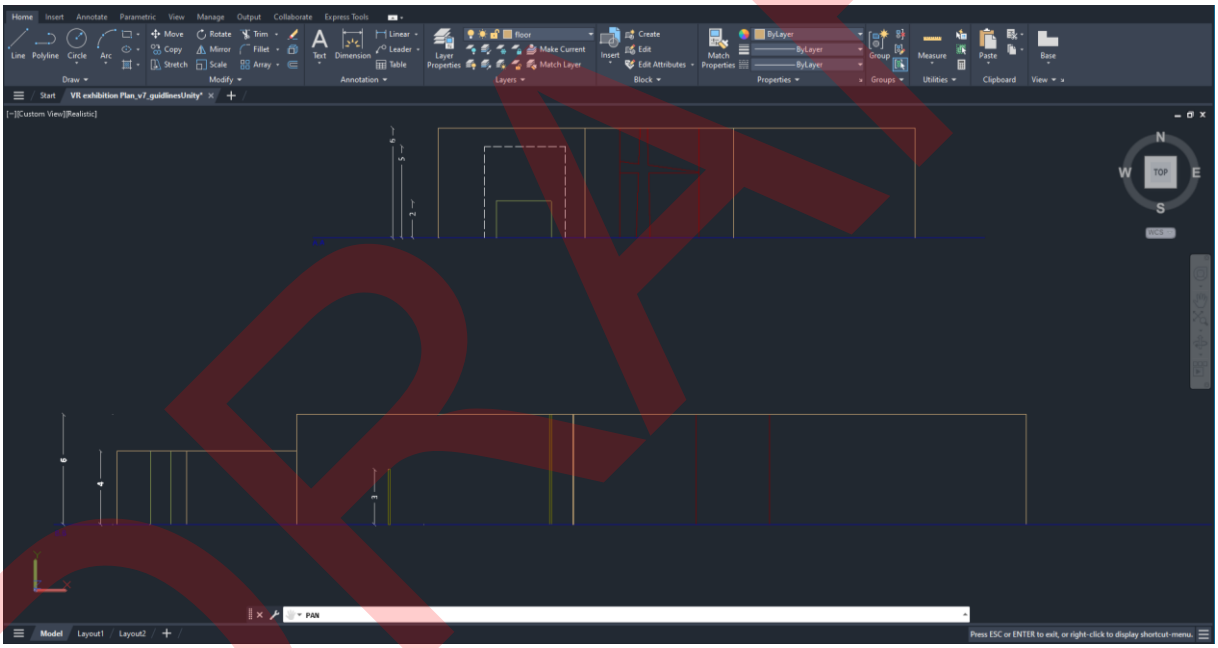

Figure 3.2.2: Two different sections of the MuseIT virtual exhibition in *AutoCAD*.

The dimensions of the virtual museum spaces have been based on the amount and scale of the exhibits (***Fig. 3.2.3)***. The architectural plan is a minimal design that is user-friendly for further exploration and orientation. To achieve a high level of aesthetic, several physical exhibitions served as inspiration for the architectural design of the spaces, including displays, textures, and lights. The figures ***3.2.4*** and ***3.2.5*** illustrate the preliminary 3D visual conceptualisation of the interior design of the exhibition, which has been designed in *AutoCAD* as well. Each of the architectural elements, such as the cross in the Religion unit or the display panels, serves the storytelling of the museum and the users' navigation. In addition, the exhibit arrangement has been defined in a way to facilitate the users' navigation and orientation as well as to embrace the museological narration.

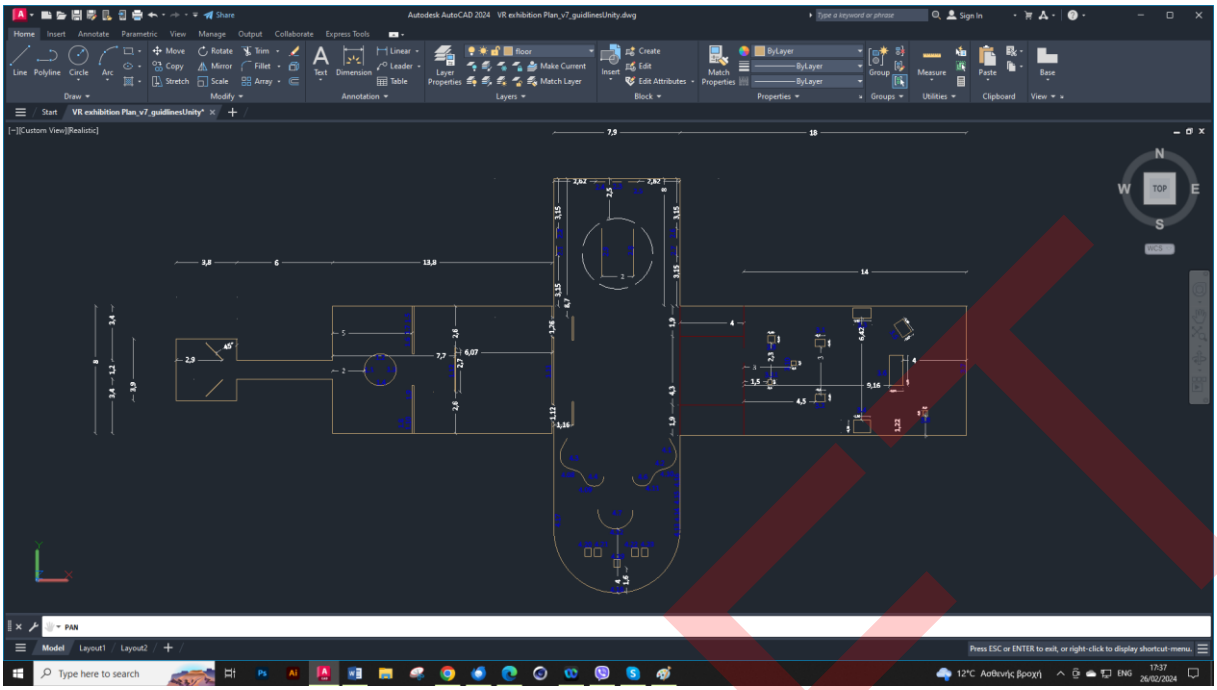

Figure 3.2.3: The exhibit arrangement and the dimensions of the spaces.

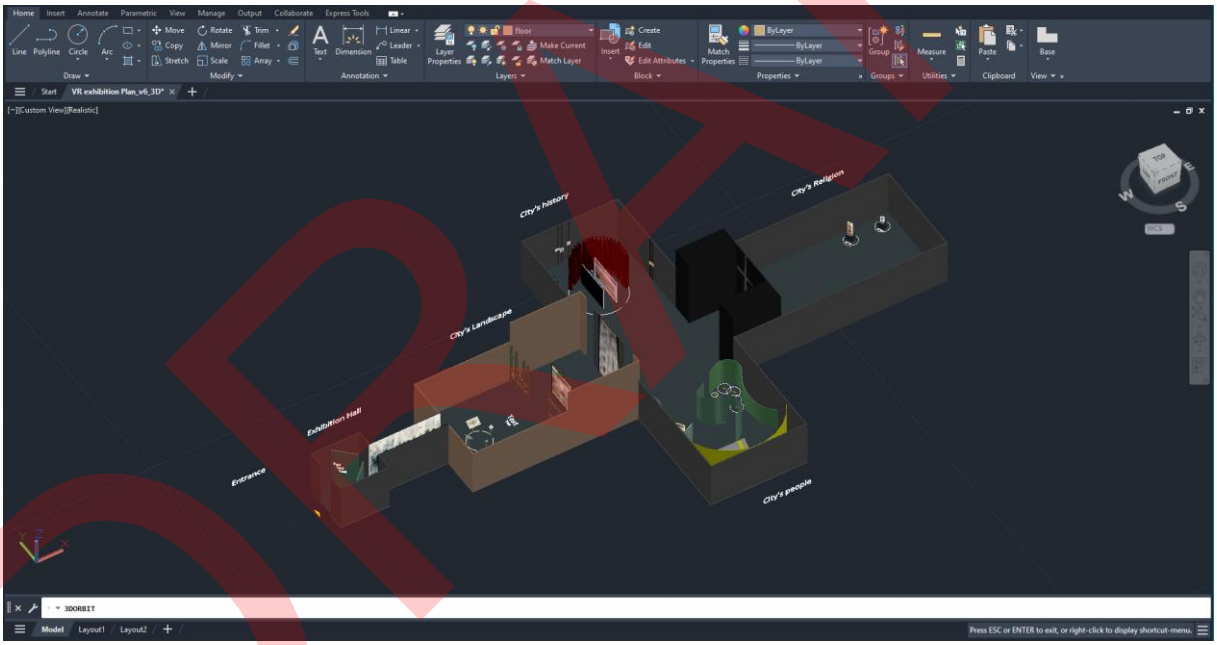

Figure 3.2.4: The preliminary 3D visual conceptualisation of the virtual exhibition.

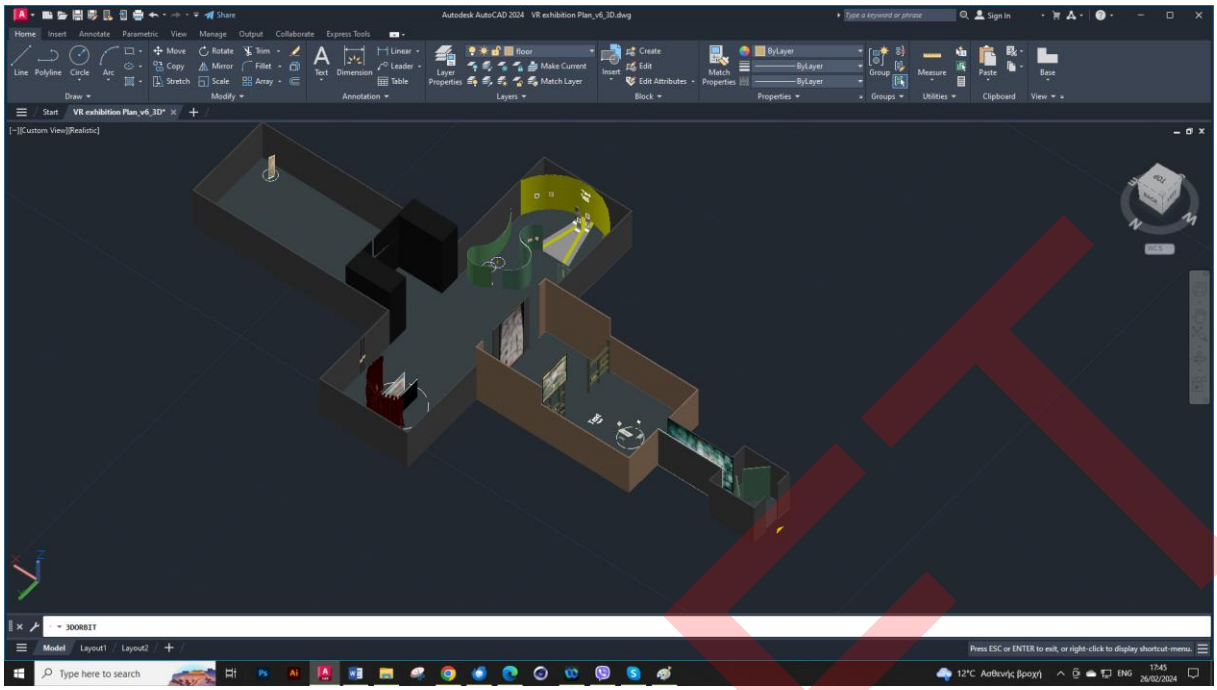

Figure 3.2.5: Another view of the preliminary 3D visual conceptualisation of the virtual exhibition.

Having determined the 2D version of the virtual exhibition and the preliminary 3D visualisation concept, the next step was the 3D modelling of the virtual experience. The software suite that was selected for the 3D modelling was *Cinema 4D* by Maxon (Cinema 4D, 2024). It is a 3D software that allows for the modelling, the texturing, and the export of a file that is compatible with the game-engine that the virtual exhibition has developed. The virtual cultural experience begins at the entrance to the space, where the user becomes familiar with the content of the exhibition units and receives the necessary instructions for using the VR controllers. The virtual exhibition has been divided into three levels of experience. The first level is the entrance to the exhibition, along with the first exhibition unit, namely the Landscape. The second level consists of the exhibition units City and History, while the third level corresponds to the unit Religion. The users will not have visibility access to the next level as long as they finish the level they explore. Having completed one level, they will be allowed to choose the next level for discovery. The separation between the first and second levels will consist of two high panels that prevent users from interacting between the two levels of experience. Additionally, the second level will be separated from the third level by a huge, cross-shaped door designed as the entrance to the Religion unit. The darkness and the focus spotlights in level 3 will prevent users from looking at the room. The 3D modelling in *Cinema 4D* has been based on the 2D architectural plan designed in *AutoCAD*, following a consistent correlation between them. Priority was given to the 3D modelling of the shell of the virtual exhibition. Thus, walls, floors, and roofs were the first elements that were designed (***Fig. 3.2.6)***. The next step was the three-dimensional design of the elements that shape and consist of the exhibition units (***Fig. 3.2.7, Fig. 3.2.8)***. These are the curved-display panels, the info panels at the entrance, the display stands, and the curtain concept. Simultaneously, the 55 cultural objects of the exhibition have been placed in 3D displays created using *Cinema 4D* as well.

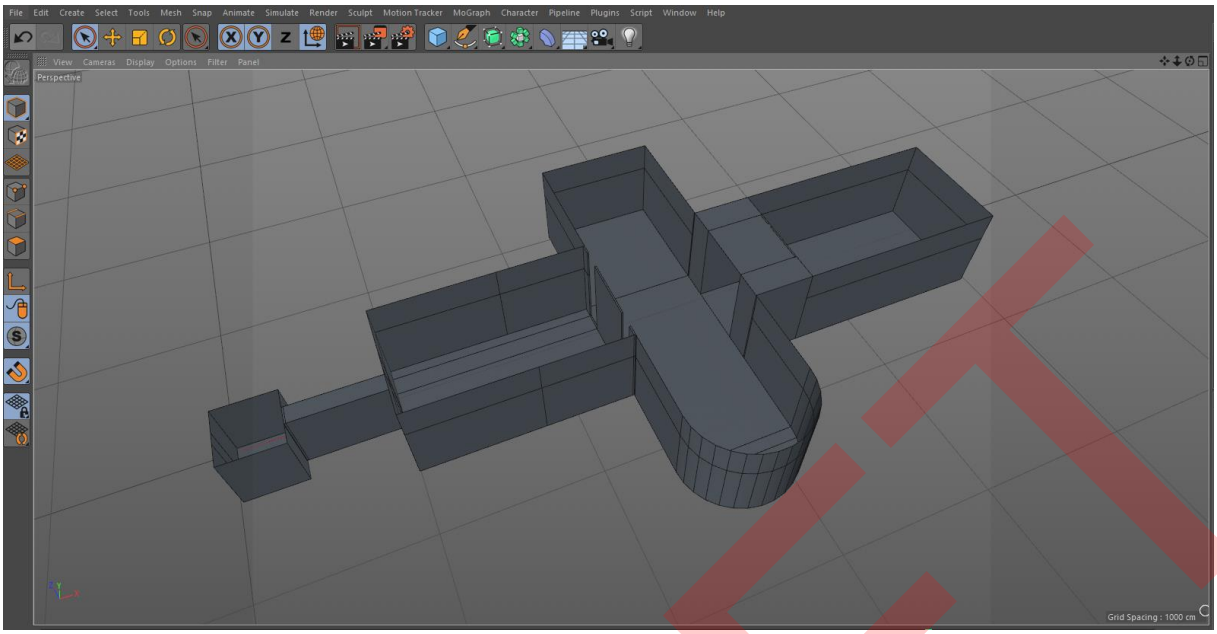

Figure 3.2.6: 3D modelling of the shell of the virtual exhibition in *Cinema 4D*.

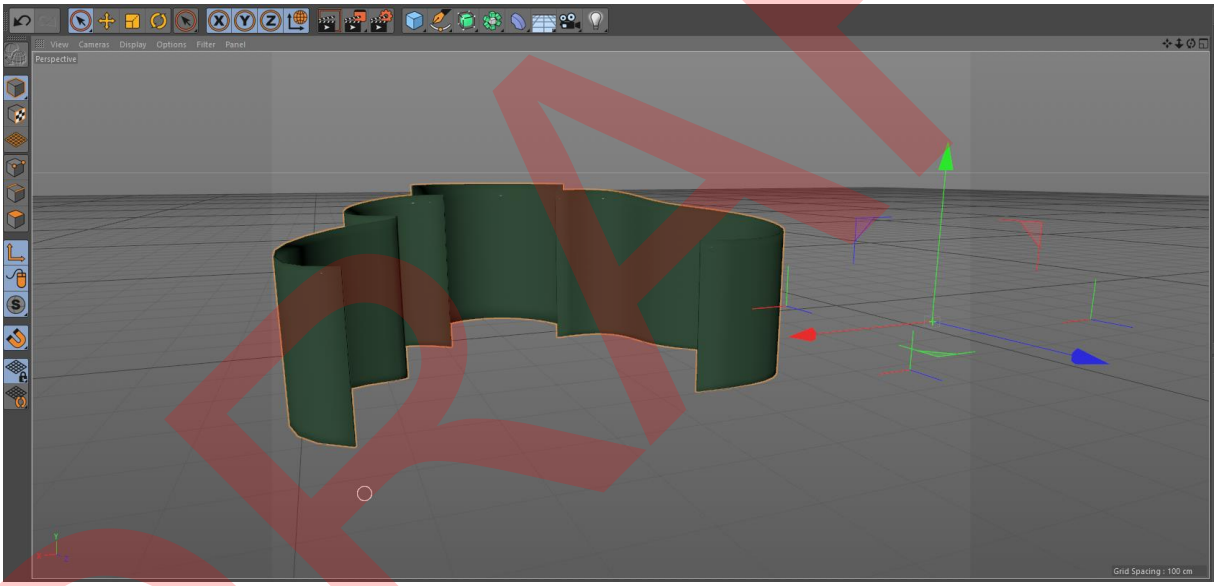

Figure 3.2.7: 3D modelling of the curved display panels in Level 2.

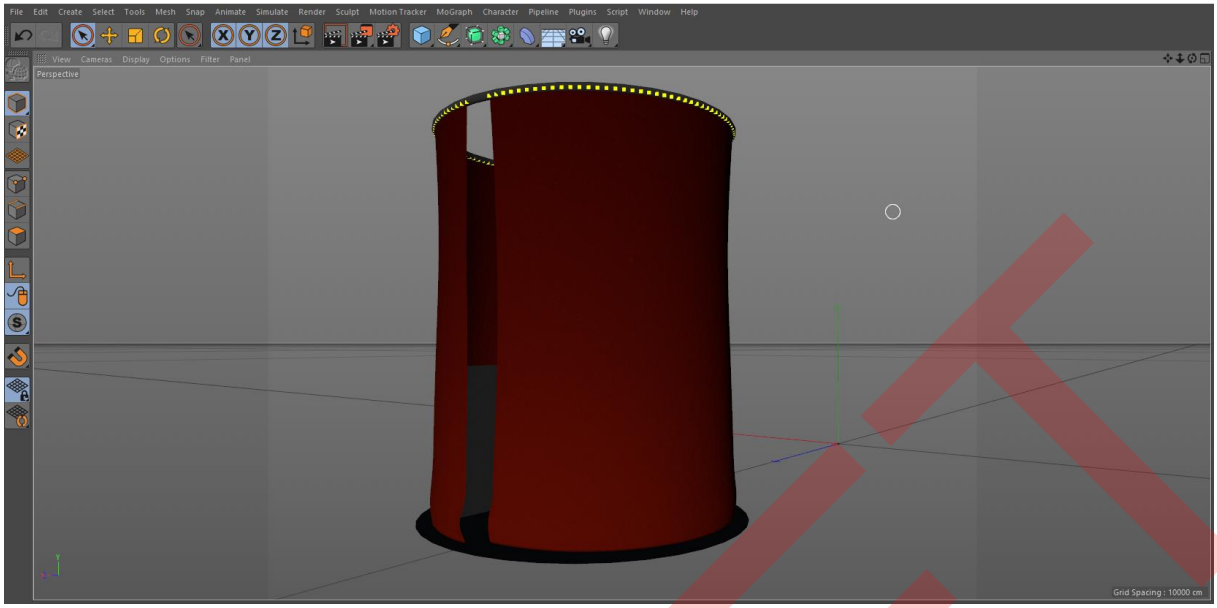

Figure 3.2.8: 3D modelling of the curtain concept in Level 2.

Following 3D modelling is the process of texturing. The aim of this step is to achieve as good a photorealism result as possible. The variety of materials used for the exhibition is limited so as not to distract the attention of the users and also to create a harmonious environment for exploration. Floors, roofs, and walls have the texture of cement, as it is a usual material in physical exhibitions. In terms of the chosen colours, the floor and the roofs of the rooms have the same material in a dark colour palette of grey, while the walls have a brighter colour palette of grey (***Fig. 3.2.9)***. On the walls of the corridor at the entrance of the exhibition have been installed two images of artefacts that will be displayed in Level 1. This element gradually introduces users to the cultural experience, igniting their curiosity for the exhibition content. For the display panels of the *People* unit, a vivid multicolor palette has been selected to highlight humans, culture, and background diversity (***Fig. 3.2.10)***. In addition, in the *History* unit, the combination of black and red symbolises the contrast of historical events during history. In addition, text has been attached to the floor surface to make the exhibition more engaging and embrace the multisensory approach. This text acts as an information element about what is displayed, helping users' interpretation of the cultural experience (***Fig. 3.2.11)***. This user is able to read or listen to the text by approaching a specific group of artefacts. Having completed the process of texturing, the next step is to bake the materials so as to successfully export *Cinema 4D* as a *.fbx* file (***Fig. 3.2.12, Fig. 3.2.13***). As depicted in ***Figure 3.2.14***, while baking an object, the path of the texture colour should be replaced with the new image. As mentioned before, text has been attached to the floor surface using *Photoshop* software by Adobe, and the image was exported from the process of *bake* (***Fig. 3.2.15***) (Adobe, 2024). Finally, the final step of the virtual museum design is to export the *Cinema 4D* file to a .fbx file in order to import it to the game-engine (***Fig. 3.2.16***).

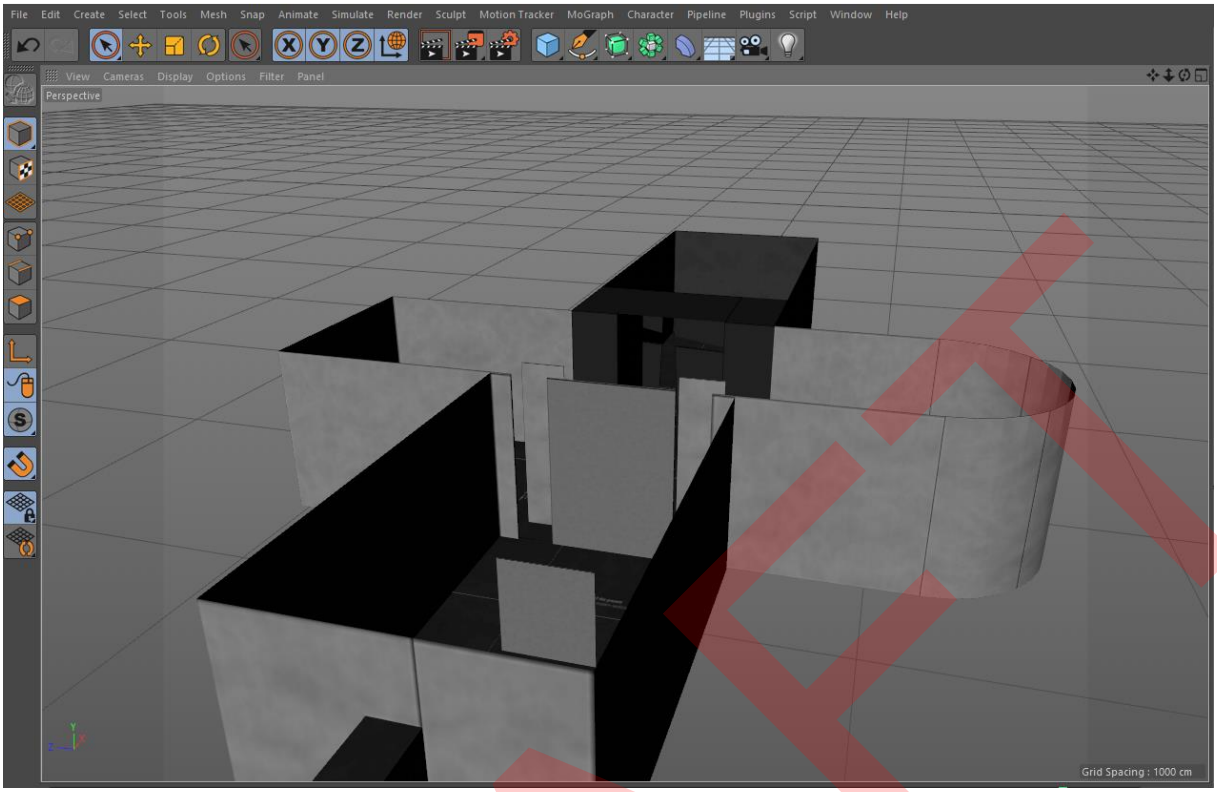

Figure 3.2.9: The colour palettes of the materials in the exhibition.

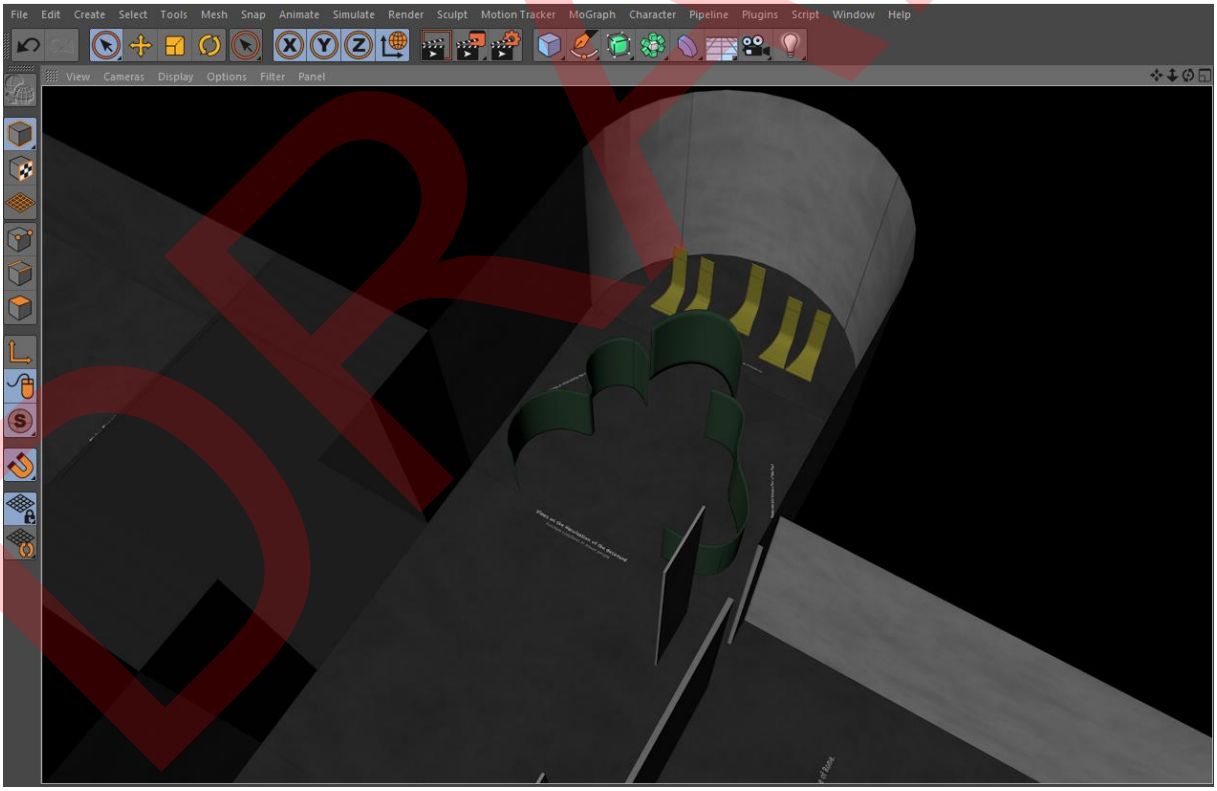

Figure 3.2.10: The curved-display panels will be in different colours palettes.

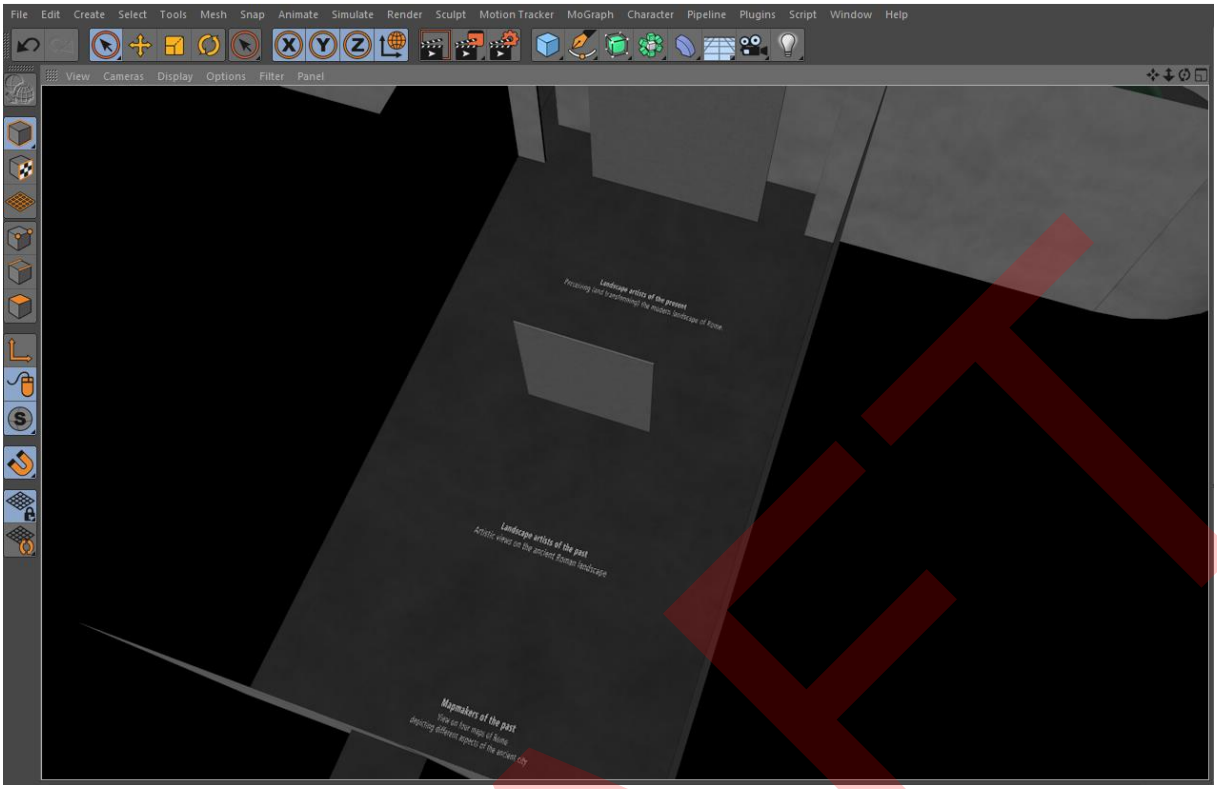

Figure 3.2.11: Example of attached text to the floor surface.

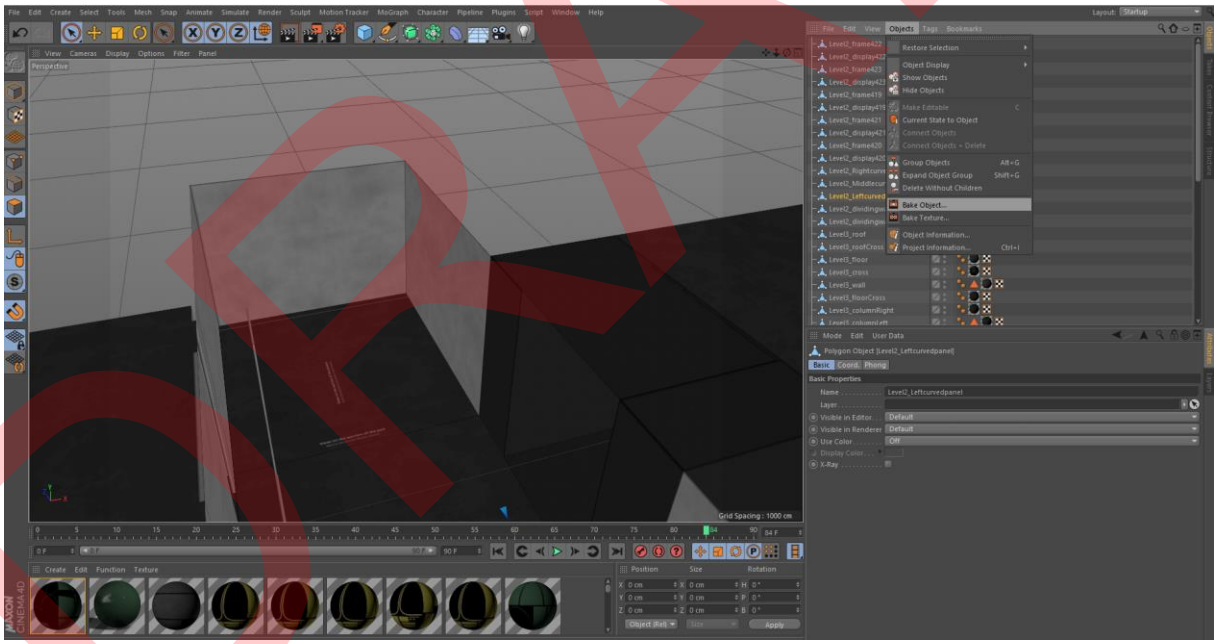

Figure 3.2.12: The selection of the bake object.

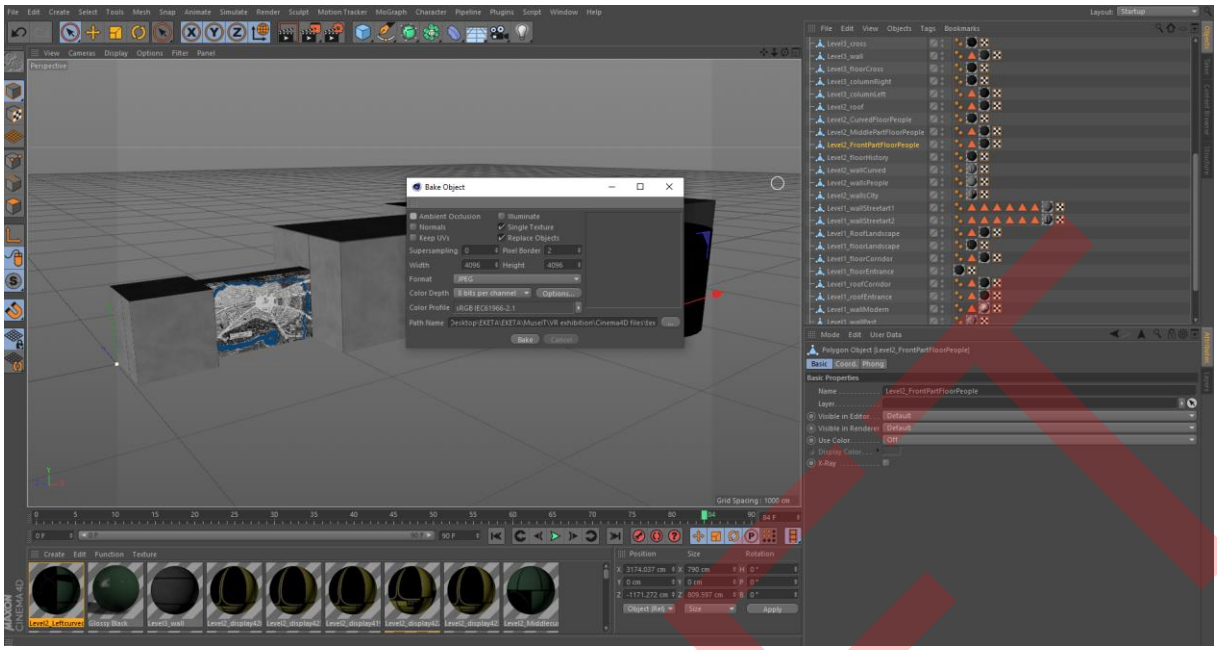

Figure 3.2.13: Bake object settings.

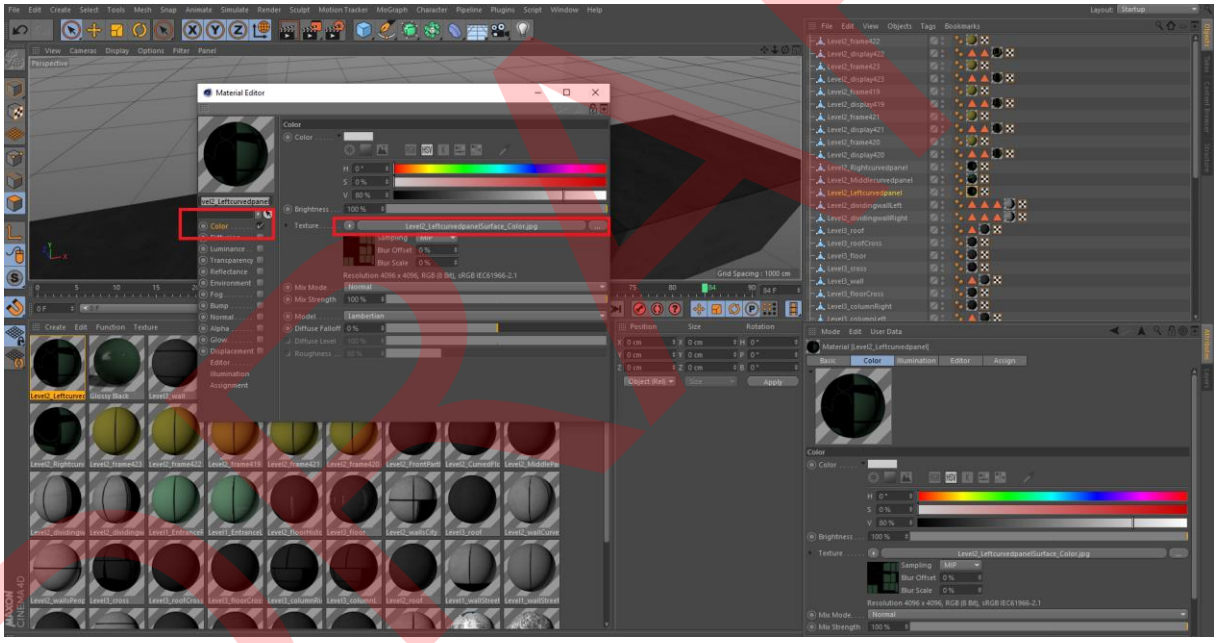

Figure 3.2.14: Replace the colour texture path with the image of the baked object.

Figure 3.2.15: Attach the text to the floor by using the *Photoshop* software.

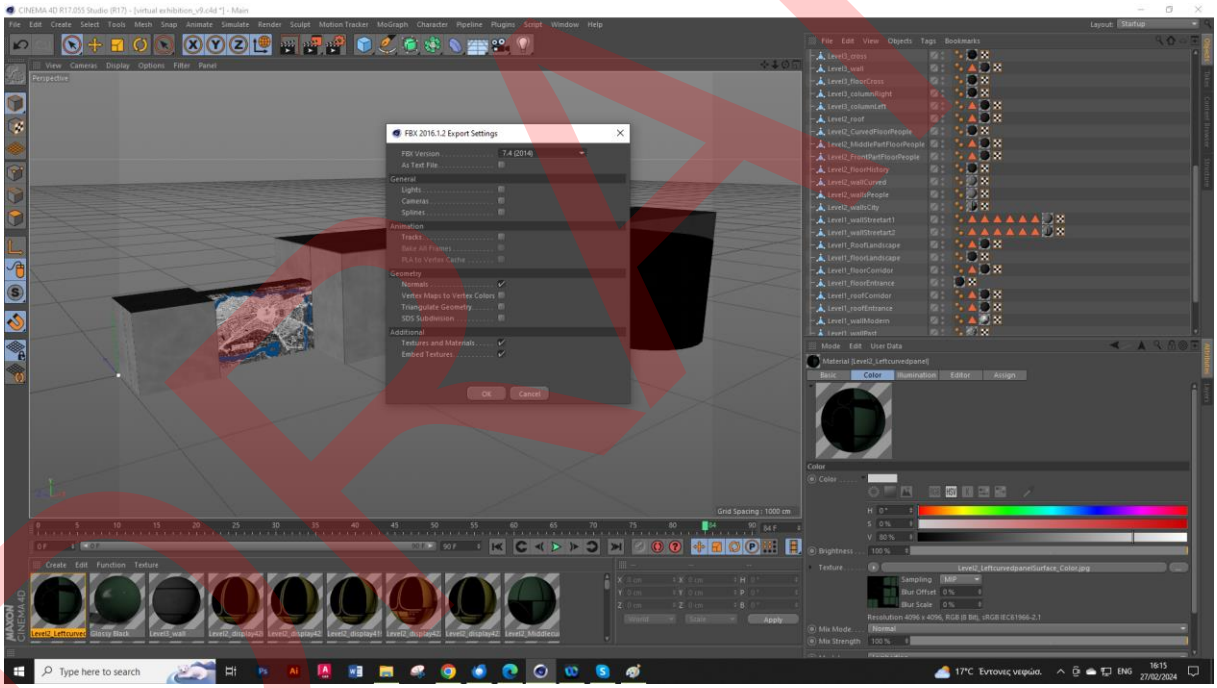

Figure 3.2.16: Setting of exporting a .fbx file in *Cinema 4D*.

3.3. XR content

This subsection describes the procedure that was followed for the creation and refinement of the XR content for the full-immersive virtual exhibition. This subsection includes the digital representation of the cultural heritage assets, as well as the 3D design of the virtual space and the associated 2D and 3D assets.

3.3.1. Cultural heritage assets

This subsection presents selected exhibits of MuseIT virtual exhibition as they are displayed in the virtual space with the use of display cases and stands that are designed from scratch (***Fig. 3.3.1.1*** - ***Fig. 3.3.1.51***). The images were rendered in *Maxon's Cinema4D*.

Figure 3.3.1.1: U1_1The plan of the village of Rome. Engraving, c.1565, Unknown artist, Rodolfo Amedeo Lanciani (contributor), 280x430 mm, Library of Archeology and Art History of Rome.

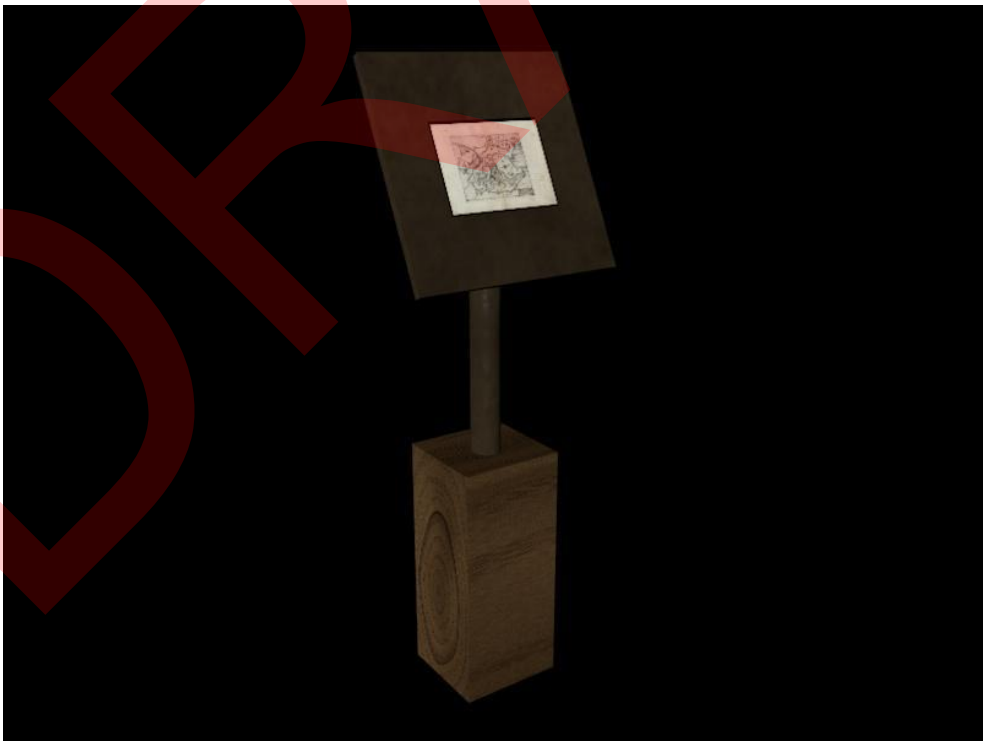

Figure 3.3.1.2: U1_2 Rome. Engraving, 1567, Ferdinand Bertelli, Rodolfo Amedeo Lanciani (contributor), 200x270 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.3: U1_3 Study of the land and the disposition of the sewers in the vicinity of the Palatine, Aventine, Capitoline, Esquiline and Celian mountains. Drawing, 19th c., Giuseppe Valadier, Rodolfo Amedeo Lanciani (contributor), 485 x 462 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.4: U1_4 Antiquae Urbis [Antiquities of the city]. Engraving, 1612-1699, Giacomo Lauro, Rodolfo Amedeo Lanciani (contributor), 245 x 180 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.5: U1_5 Via Circi Maximi. Engraving, 1556, Marco Fabio Calvo, 265x375 mm, Library of Archeology and Art History of Rome; U1_7 Roman Forum, Panorama. Engraving, 1790, Unknown artist, Rodolfo Amedeo Lanciani (contributor), 561x844 mm, Library of Archeology and Art History of Rome; U1_6 View of the Roman Forum from the east. Drawing, 19th c., Unknown artist, Rodolfo Amedeo Lanciani (contributor), 229x378 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.6: U1_8 Colosseum, exterior. Drawing, 1836, Luigi Rossini, Rodolfo Amedeo Lanciani (contributor), 282x425 mm, Library of Archeology and Art History of Rome; U1_9 View of the Colosseum from Palatine Hill. Drawing (watercolour, pen and brown ink), 1780-1781, Francis Towne, Rodolfo Amedeo Lanciani (contributor), 370x535 mm, Library of Archeology and Art History of Rome;

U1_10 General view of the central and eastern area of the Roman Forum taken from the via del Campidoglio. Photograph, 20th c., Unknown photographer, Rodolfo Amedeo Lanciani (contributor), 185 x 241 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.7: U1_12 Soul city. Mural, 2015, Maupal, GoTellGo Cultural Association.

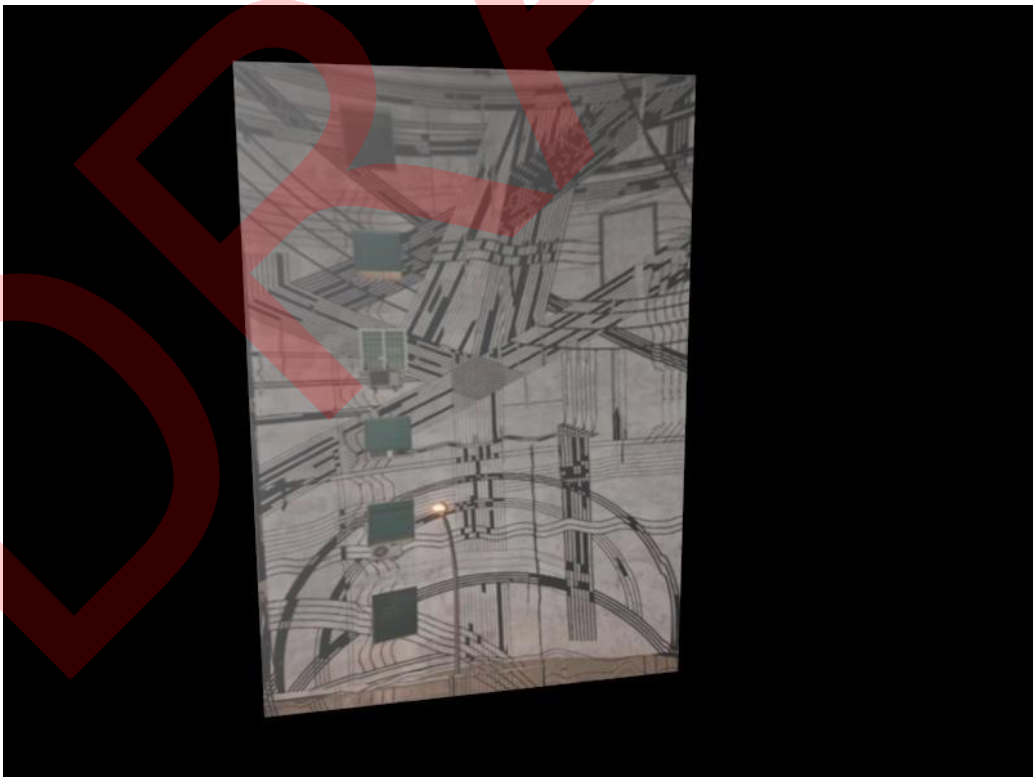

Figure 3.3.1.8: U1_11 Abstract landscape. Mural (Stencils), 2013, Sten & Lex, GoTellGo Cultural Association.

Figure 3.3.1.9: U2_1 "Hostilia arma, cassides, clypei, peltae, loricae, arcvs, pharetrae barbarorvm trophaea. Item avrvm signatvm, et praeda victarvm gentivm, et regvm. Andreas Mantinea pinxit Mantuae" * Triumph scene from the work "C. Iulii Caesaris dictatoris triumphi de Gallia, Aegypto, Ponto, Africa, Hispania, quinquies eodem mense triumphantis; omnium, qui unquam fuere, Ducum, Regum Bellica virtute praestantissimi ab Andrea andrea Mantinea eximio, atque insigni Pictori Mantuae" * Rome, Domenico de Rossi, 1692". Engraving, 1692, Robert van Audenaerde after Andrea Mantegna's paintings, workshop of Domenico de Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 390x410 mm circa, Library of Archeology and Art History of Rome.

Figure 3.3.1.10: "Tabula marmorea, pugnae Dacicae: ex diruto Traiani; ut putatur; arcu; in Constantini cognomento Magni; qua Spectat Aventinum; ornatus caussa; Romae translata. Antonii Lafrerii Seguani formis Romae 1553 " * "Marble picture of the Battle of Dacia; from the arch of Trajan, demolished, so it is believed, in the name of Constantine the Great; from which one observes the Aventine Hill; for the sake of ornamentation; transported to Rome" * From the work "C. Huelsen, Das Speculum Romanae Magnificentiae des Antonio Lafreri, in Collectanea variae Riferinae Leoni S. Olschki..., Monachii 1921, n. 16a;". Engraving, 1553, Nicolas Beatrizet, Antonio Lafrery (Rome, printer), Rodolfo Amedeo Lanciani (contributor), 272x380 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.11: U2_3 TRIUMPHI, uti L. Paulus de rege Macedonum Perse capto, P. Africanus Aemilianus de Carthagenensibus excisis, C.N. Pompeius Magnus ex oriente, Julius Augustus, Vespasianus, Trajanus et alii imperatores Romani, triumpharunt. Ex antiquissimis lapidum, nummorum et librorum monumentis accuratissima descriptio {BVE0818734} " * "The most extensive and most decorated triumph, as L. Paulus continued to capture the king of the Macedonians, P. Africanus Aemilianus cut off from the Carthaginians. BC Pompey the Great from the East, Julius Augustus, Vespasian, Trajan, and other Roman emperors triumphed. A detailed description of the most ancient records of stones, coins and books {BVE0818734}. Engraving, 1648-1677, Giovanni Giacomo Rossi (printer), 156x360 mm, Library of Archeology and Art History of Rome

Figure 3.3.1.12: U2_4 "Vnus ex transfugis e' Dacia ad occidentum Traianum in Missam profectus, ab suspicionem captus, Imperatori defertur, cui Decebali patefacit insidias. Dion ex'phil" from the work "Icones et segmenta illvstriuvm e marmore tabvlarvm qvae Romae adhvc extant a Francisco Perrier, delineata incisa et ad antiqvam formam lapideis exemplaribvs passim collapsis restitvta" (Taf28). Engraving, 1638-1660, Perrier François, Rodolfo Amedeo Lanciani (contributor), 303x220 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.13: U2_5 "Traianus Pont. Max. habitu pateram tenens ante accensam Tripodem celebrat suo oue taurilia in uictimas coesurus Taurum Joui...Matteo Piccioni Fecit". From the series "Low ancient reliefs in Constantine's arc, and in Campidoglio". Engraving, 1655, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 278x205 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.14: U2_6 "Militum Praefectus Tribunosq. e suggestu Traianus alloquitur... M.° Piccioni fecit" At the right bottom "ex Arcu Costantini". Engraving, 1655, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 278x204 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.15: U2_7 Trajan returned to Rome and promising peace to the ambassadors of supplicant barbarians. * "M.° Piccioni fecit." At the right bottom, "ex Arcu Costantini". Engraving, 1650, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 280x200 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.16: U2_8 Warriors. Mural, 2007, Unknown artist, GoTellGo Cultural Association.

Figure 3.3.1.17: U2_9 The last battle (L'ultima battaglia). Mural, 2013, Stephanie Fabrizi, GoTellGo Cultural Association.

Figure 3.3.1.18: U3_1 Madonna delle Concanelle. Sculpture, 1262, Magister Machilonus and son, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.19: U3_2 Enthroned Madonna with the Child. Sculpture, c.1340, Master of Santa Caterina Gualino, 116cm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.20: U3_3 Pope San Pietro Celestino. Sculpture, late 15th c. Saturnino Gatti (attributed), 110cm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.21: U3_4 Madonna with the Child. Sculpture, 1506, Saturnino Gatti, 116cm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.22: U3_5 Saint Athony the Abbot. Sculpture, 1512, Saturnino Gatti, 140cm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.23: U3_6 Holy Family Group. Sculpture, late 15th - early 16th c., Saturnino Gatti, 100-110cm., MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.24: U3_7 Migrant 4 life. Poster street art. 2018, Qwerty, GoTellGo Cultural Association.

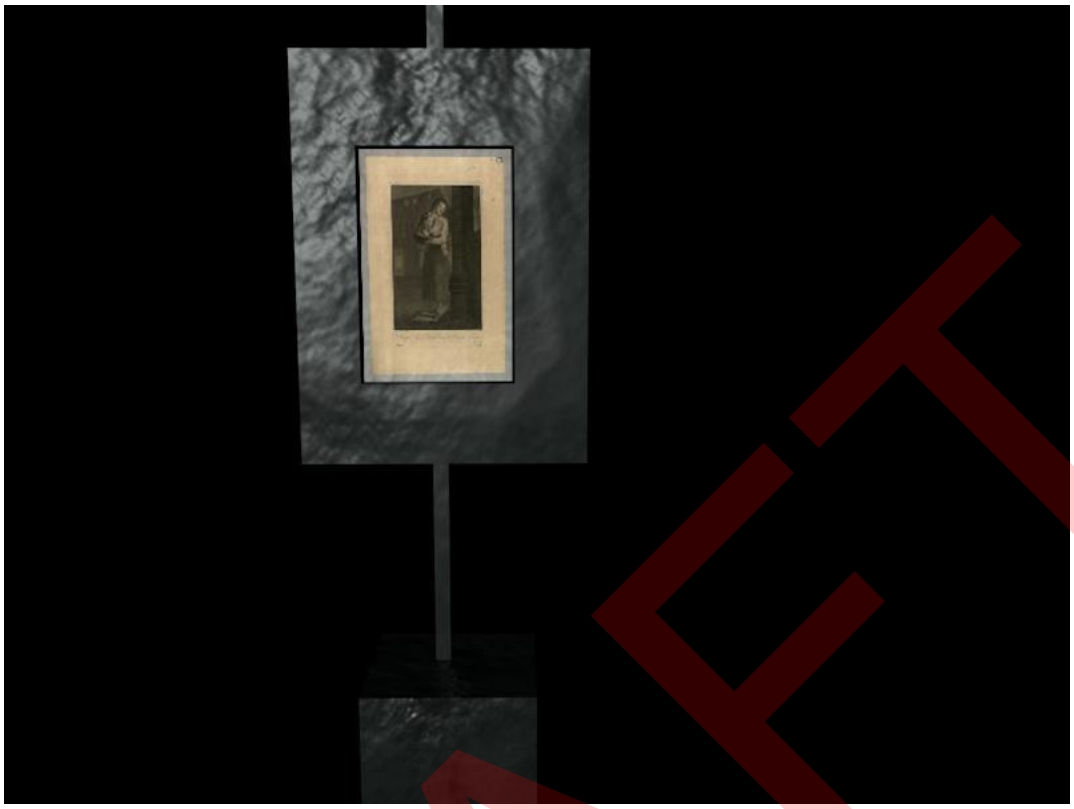

Figure 3.3.1.25: U3_8 Imago Servi Dei Benedicti Joseph Labre / Nic.us La Piccola inv. et pinx. , Franc. Barbazza sculp. Engraving, 1788, 400x265 mm, Francesco Barbazza, Rodolfo Amedeo Lanciani (contributor), Niccolò Lapiccola (contributor), Library of Archeology and Art History of Rome.

Figure 3.3.1.26: U3_9 Resting Hercules, sculpture, 3rd c. BC, 39cm, National Archaeological Museum of Abruzzo Villa Frigerj.

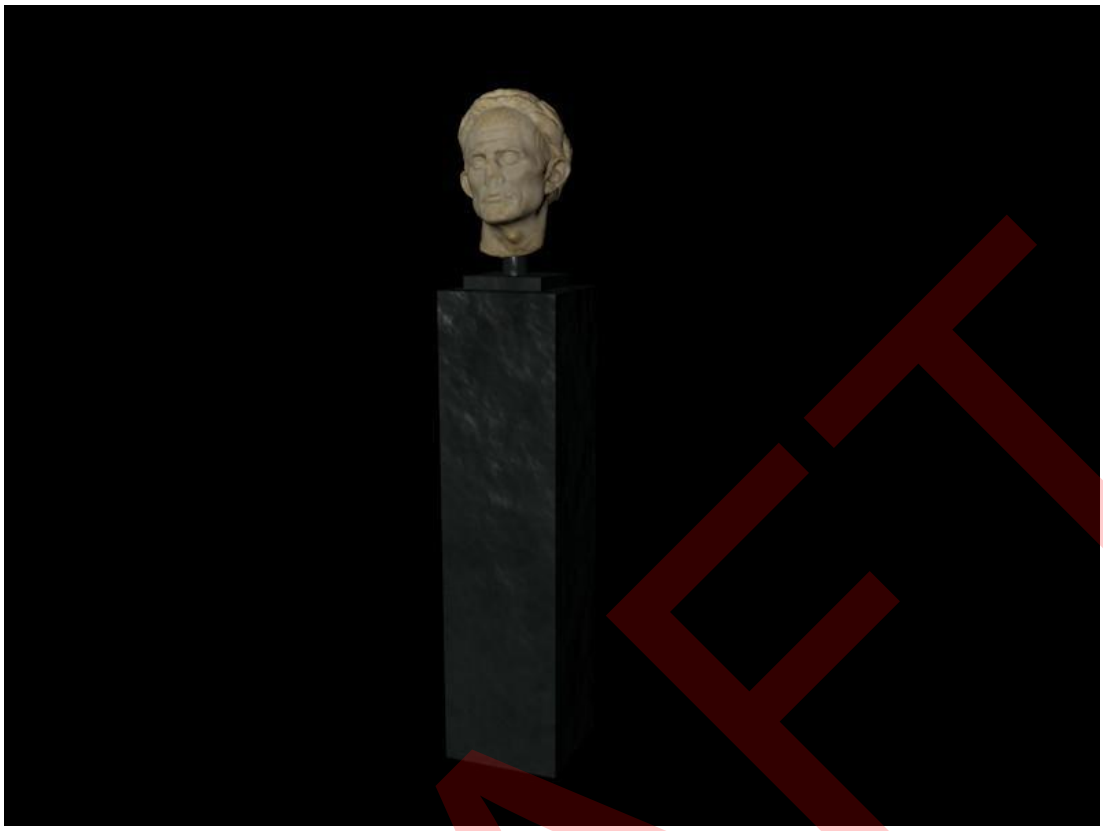

Figure 3.3.1.27: U3_10 Roman portrait of an old man, Sculpture, 146-31 BC., 32cm, MUNDA-National Museum of Abruzzo, L'Aquila.

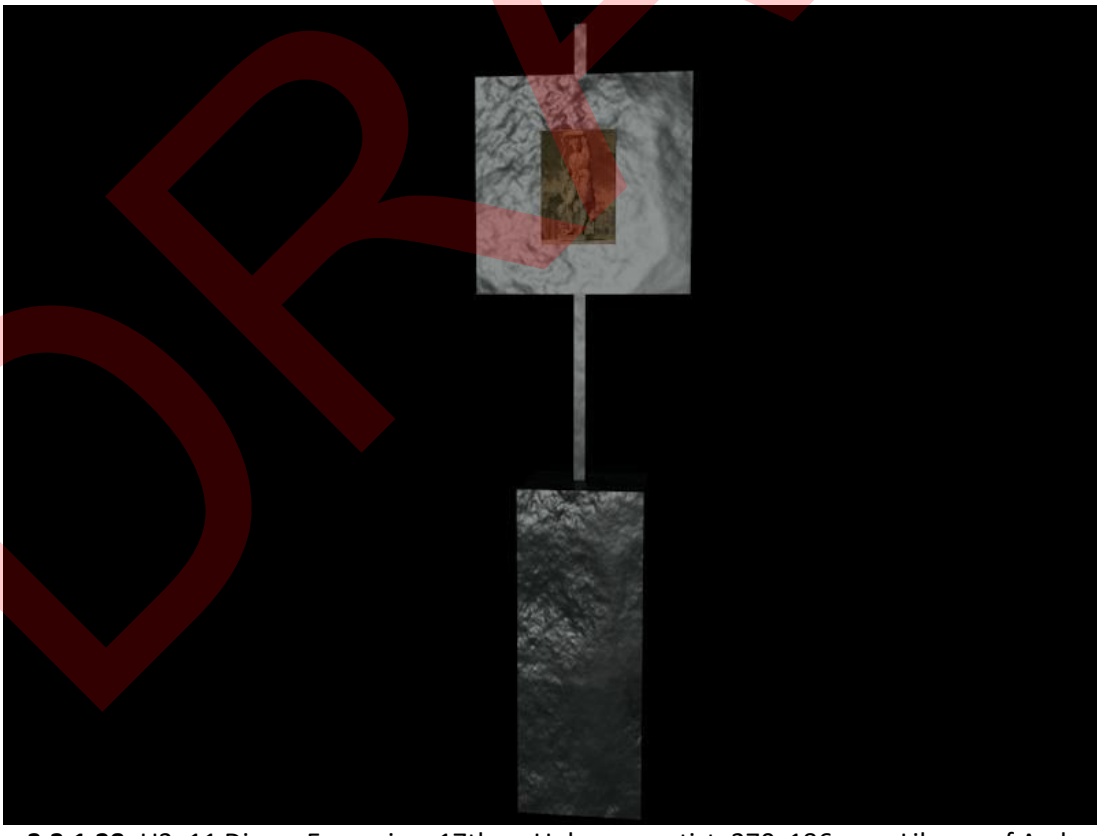

Figure 3.3.1.28: U3_11 Diana, Engraving, 17th c., Unknown artist, 270x186 mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.29: U4_1 Stele de Guardiagrele. Funerary sculpture, 7th c. BC, 80 cm, MUNDA-National Museum of Abruzzo, L'Aquila.

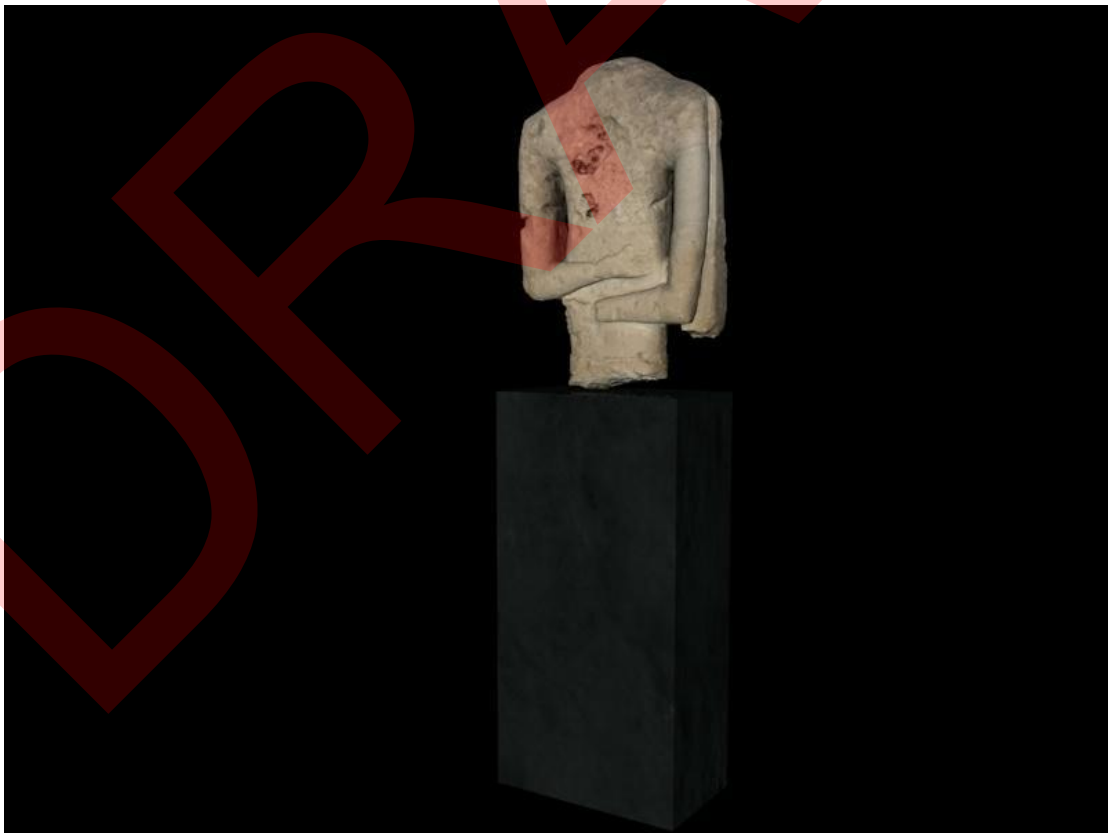

Figure 3.3.1.30: U4_2 Torso di Adessa. Funerary sculpture, 7th c. BC, 80 cm, MUNDA-National Museum of Abruzzo, L'Aquila.

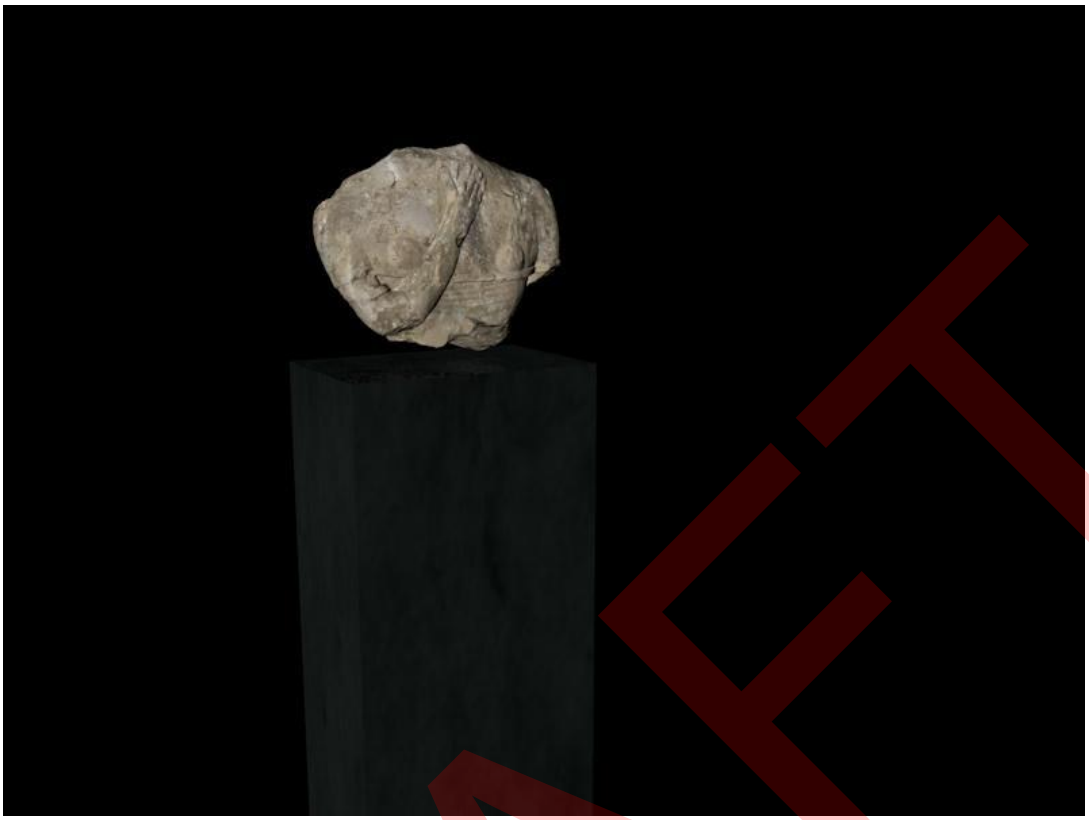

Figure 3.3.1.31: U4_3 Dama di Capestrano. Funerary sculpture, 6th c. BC, 30 cm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.32: U4_4 Warrior di Capestrano. Funerary sculpture, 6th c. BC, 209 cm, MUNDA-National Museum of Abruzzo, L'Aquila.

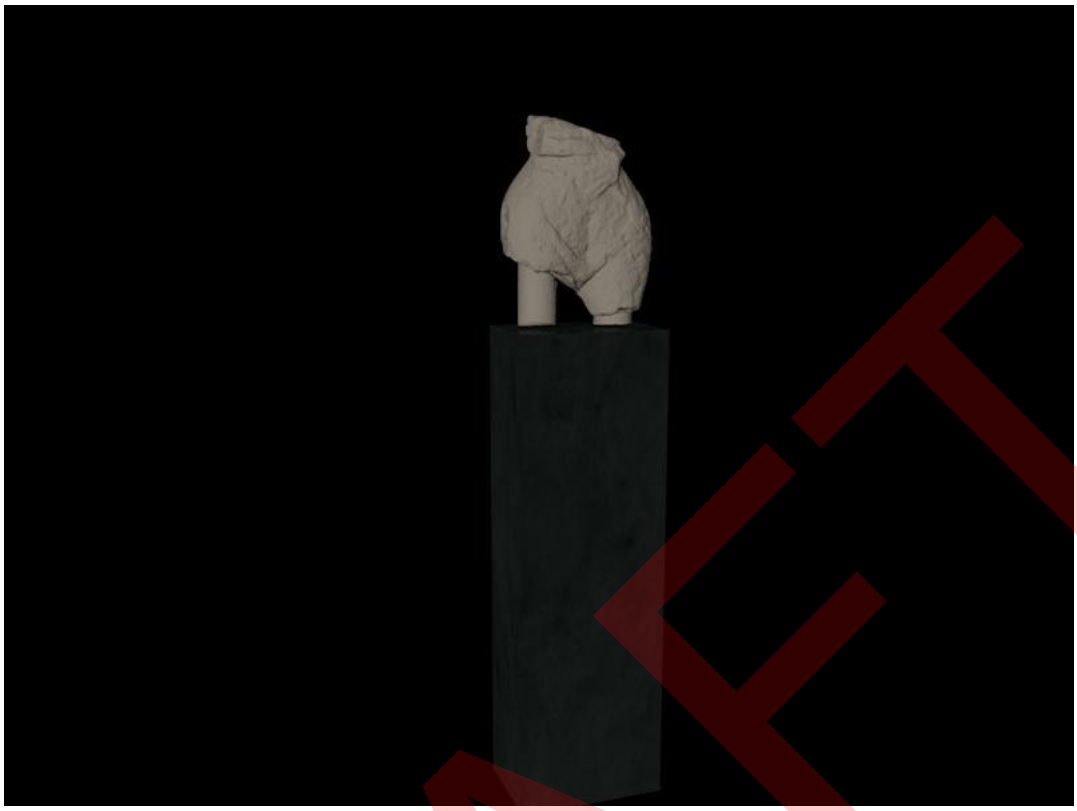

Figure 3.3.1.33: U4_5 Torso di Rapino. Funerary sculpture, 6th c. BC, MUNDA-National Museum of Abruzzo, L'Aquila.

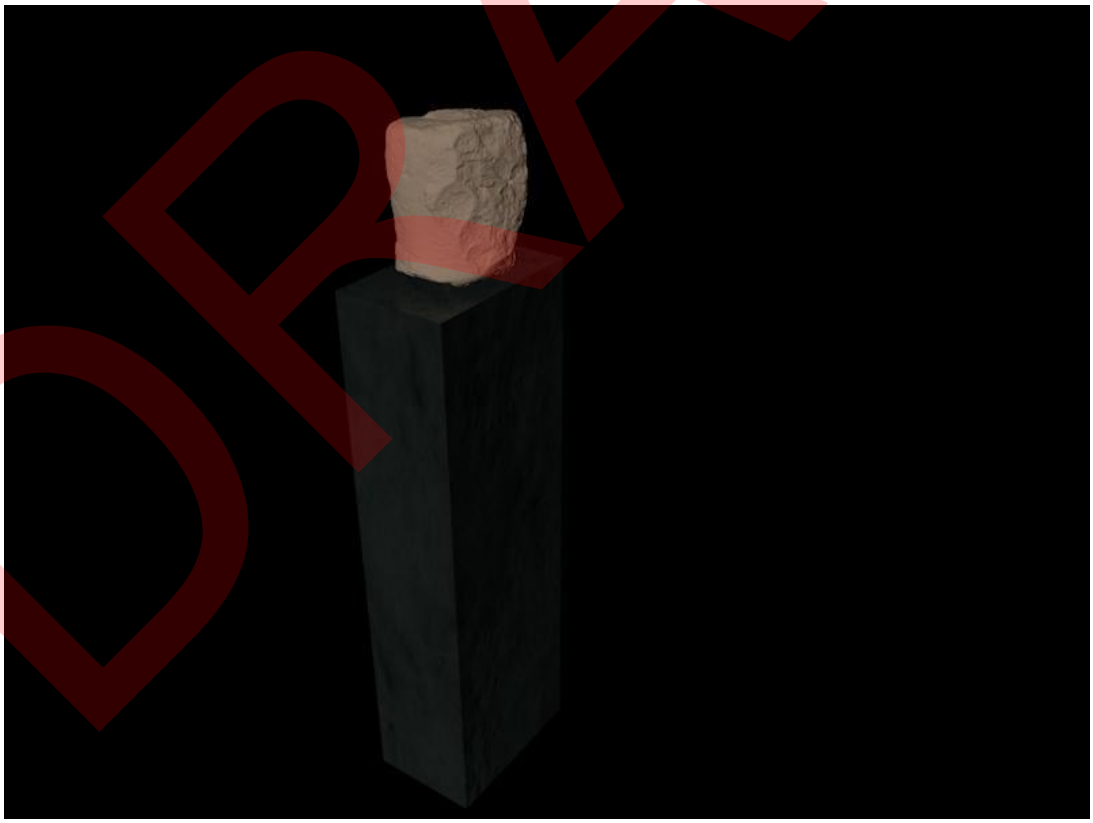

Figure 3.3.1.34: U4_6 Head di Manopello. Sculpture, 6th c.-5th c. BC, 327mm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.35: U4_7 Stele of Penna Sant' Andrea 1. Funerary sculpture, 5th - 4th c. BC, 218 cm, MUNDA-National Museum of Abruzzo, L'Aquila.

Figure 3.3.1.36: U4_8 Depiction of the twins Castor and Pollux and Concordia. Engraving, 17th c., 272 x 205mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.37: U4_9 "Caesar avreo cvrrv insignis ad Capitolivm trivnphans incedit retro victoria eivs capiti lavream imponit praeevnte celebra titvlo Veni Vidi Vici", Triumph scene from the work "C. Iulii Caesaris dictatoris triumphi de Gallia, Aegypto, Ponto, Africa, Hispania, quinquies eodem mense triumphantis; omnium, qui unquam fuere, Ducum, Regum Bellica virtute praestantissimi ab andrea Mantinea eximio, atque insigni Pictori Mantuae" * Rome, Domenico de Rossi, 1692". Engraving, 1692, Robert van Audenaerde after Andrea Mantegna's paintings, workshop of Domenico de Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 385x415mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.38: U4_10 "[Simolacri ex arcu Costantini] Ill:mo cul...] Pio di Sau.ia [...] Simolacri più veri, che quelli delli antichi Suoi fasti, consacro questo uolume a V. S. Ill.ma ... Mattheo Piccioni / Matheius Piccionius Inventor fecit." Engraving, 1650, Matteo Piccioni, Giovanni Giacomo Rossi (printer), Rodolfo Amedeo Lanciani (contributor), 275x192mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.39: U4_11 Inscription used by the architect to make the period of the main restorations visible in the underground arena of the Flavian amphitheatre. Engraving, 18th c., 290x230mm, Library of Archeology and Art History of Rome.

Figure 3.3.1.40: U4_12 Gorgeous mother of the Resistance feed me your essence. Poster Street Art, 2015, Ex-voto, GoTellGo Cultural Association.

Figure 3.3.1.41: U4_13 Garibaldi. Poster Street Art, 2011, GoTellGo Cultural Association.

Figure 3.3.1.42: U4_14 Our lady of football. Poster Street Art, 2014, Ex-voto, GoTellGo Cultural Association.

Figure 3.3.1.43: U4_15 Maria Vergine Augusta.Poster Street Art, 21st c., Ex-voto, GoTellGo Cultural Association.

Figure 3.3.1.44: U4_16 Male portrait, Mural, 2008, C215, GoTellGo Cultural Association.

Figure 3.3.1.45: U4_17 Tribute to the Gospel according to Matthew by Pasolini. Mural, 2013, Mr Klevra, GoTellGo Cultural Association.

Figure 3.3.1.46: U4_18 Vittorio De Sica - Umberto D. Poster Street art, 2009, Zilda, GoTellGo Cultural Association.

Figure 3.3.1.47: U4_19 Toto. Poster Street art, 2009, Zilda, GoTellGo Cultural Association.

Figure 3.3.1.48: U4_20 Melting Icons: Anna Magnani. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association.

Figure 3.3.1.49: U4_21 Melting Icons: Sergio and Franco Citti. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association.

Figure 3.3.1.50: U4_22 Melting Icons: Mario Monicelli. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association.

Figure 3.3.1.51: U4_23 Melting Icons: Pier Paolo Pasolini. Mural, 2014, David 'Diavù' Vecchiato, GoTellGo Cultural Association.

3.3.2. XR content creation

Apart from the artefacts and the building of the virtual museum a set of additional assets were designed in a 3D software package. The development of additional XR content was based in the following 3D modelling methodologies:

- **Polygon** modelling.
- **Revolution** modelling.
- **Boolean** modelling.

Regarding the texturing of the 3D models, we applied materials from the software package. We applied the Baking method and exported them as FBX files, ready for use in the *Unity 3D* game engine.

3.4. Development of the virtual museum

This subsection presents some key-points during the phase of the development for the first edition of the virtual museum for the MuseIT project.

3.4.1. Game engine

The game-engine that was selected for the development of the full cultural heritage experiences was *Unity 3D*. Through the *Unity Hub*, which is a manager for multiple installations of the *Unity Editor*, the edition *Unity 2022.3.20f1* was selected, as this was the most recent version that provides long term support (LTS) (***Fig. 3.4.1.1***). The game-engine was installed on a desktop PC, with *MS Windows 10* operating system and 64-bit architecture.

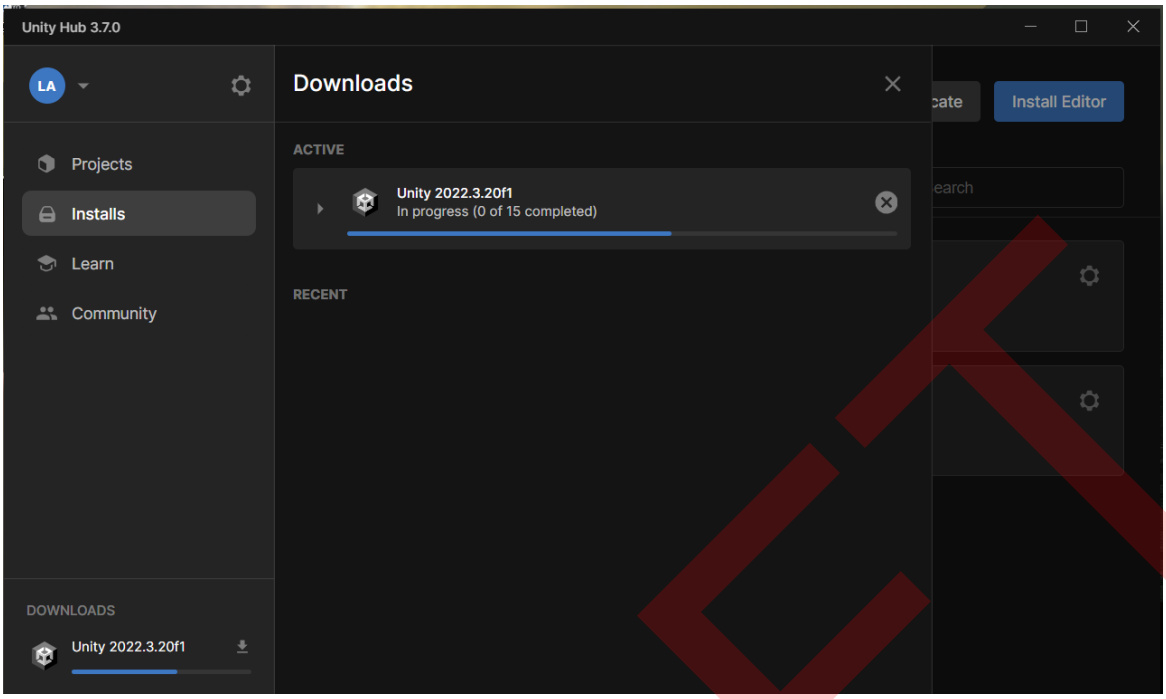

Figure 3.4.1.1: Downloading and installing the *Unity Editor* in MS Windows desktop computer.

Regarding the system that was used for the development of the virtual museum: Intel(R) Core(TM) i9-9900K CPU, @3.60GHz. In addition, the GPU of the system: *NVIDIA GeForce RTX 3080*, 12GB.

3.4.2. Virtual reality equipment

The VR equipment that was used for the development of the virtual museum for the MuseIT project (1st edition) was the *Oculus Rift S* (***Fig. 3.4.2.1***).

Figure 3.4.2.1: The Oculus Rift S head mounted display (HMD) with its touch controllers.

VR development shares common workflows and design considerations with any real-time 3D development in *Unity*. We used the *XR Plug-in Management system* to install and enable XR provider plug-ins for the selected device. The *Oculus XR plugin* enables it to build applications for a variety of Oculus devices including the *Rift*, *Rift S*, *Quest 2*, Quest Pro, and *Quest 3*. The input subsystem provides controller support, haptic feedback for touch controllers, and tracking for the controllers and HMD.

Integration with *XR Management* is not required to use the *Oculus XR plugin*, but it provides for a simpler and easier way of using this and other providers within *Unity*. The *Oculus XR plugin* package

ships with built-in *XR Management* support. The *Oculus XR plugin* integration with *XR Management* provides the following functionality:

- **Runtime Settings**: Configure runtime settings such as rendering modes, depth buffer sharing, Dash support, etc.
- **Lifecycle Management**: The *Oculus XR plugin* ships with a default XR plugin loader implementation that handles subsystem lifecycle such as application initialization, shutdown, pausing, and resuming.

For standalone PC VR, numerous interaction profiles are already configured for the user (***Fig. 3.4.2.2***).

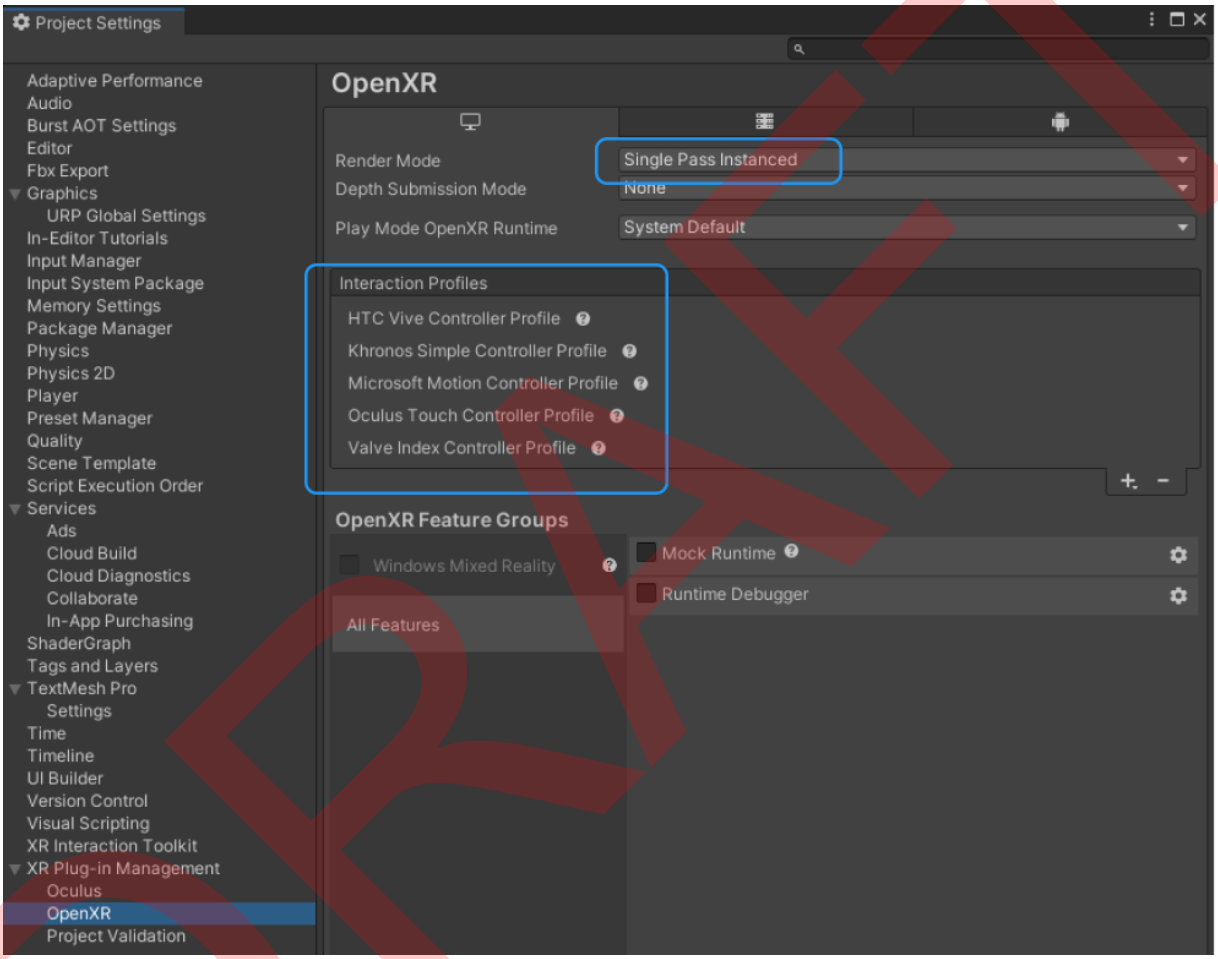

Figure 3.4.2.2: Project settings for VR development in *Unity*.

3.4.3. Development of cultural heritage exhibition in VR

In this subsection we describe some representative key aspects that we have included in the first version of the full-immersive cultural heritage exhibition in virtual reality. VR development in *Unity* includes the following factors:

- **Richer user input**: in addition to traditional button and joystick controllers, VR devices provide spatial head, controller, and (in some cases) hand and finger tracking.
- **More intimate interaction with the environment**: in conjunction with the possibilities of richer input, VR raises the expectations of much closer and physical interaction with the environment than typical 3D games and applications. Users expect to be able to pick things up through the touch controllers and interact with objects in the environment. With head

tracking, the camera can get much closer to the walls and other boundaries of the environment – even passing through them.

- **User comfort concerns**: many people experience motion sickness in VR when camera movement does not match the movement of their head. We can mitigate the causes of motion sickness by maintaining a high frame rate, offering a range of locomotion options so that users can choose a mode they are comfortable with, and avoiding moving the camera independently of the user's head tracking.

Most of the features and APIs used for VR development in *Unity* are provided through packages. These packages include:

- **Provider plugins**: To build VR apps in *Unity*, use the XR plugin Management system to add and enable provider plug-ins for the devices you want to support.
- **XR Interaction Toolkit**: The XR Interaction Toolkit can make it easier and faster to develop VR applications.
- **XR Core Utilities**: The XR Core Utilities package contains software utilities used by other *Unity XR* plug-ins and packages. Typically, this package gets installed in your project as a dependency of other XR packages.
- **Input System**: The *Unity Input System* package not only supports accessing user input from VR controller buttons and joysticks, but also provides access to XR tracking data and haptics. The Input System package is required if you use the XR Interaction Toolkit or the OpenXR provider plug-in.
- **VR project template**: *Unity's VR Project Template* provides a starting point for virtual reality development in *Unity*. The template configures project settings, pre-installs the right packages, and includes a sample scene with various pre-configured example assets to demonstrate how to set up a project that is ready for VR.
- **Hand tracking**: Hand tracking is a feature that allows users to interact with a VR application using their hands. Hand tracking is supported by the XR Hands package. It simulates the touch controllers with virtual hands.

Various presets are used to accommodate graphics & rendering requirements for different platforms. By selecting the target platform in the Build Settings, i.e. Windows, Mac, Linux or Android, different Universal Render Pipeline (URP) Config Settings are automatically updated for the user (***Fig. 3.4.3.1***).

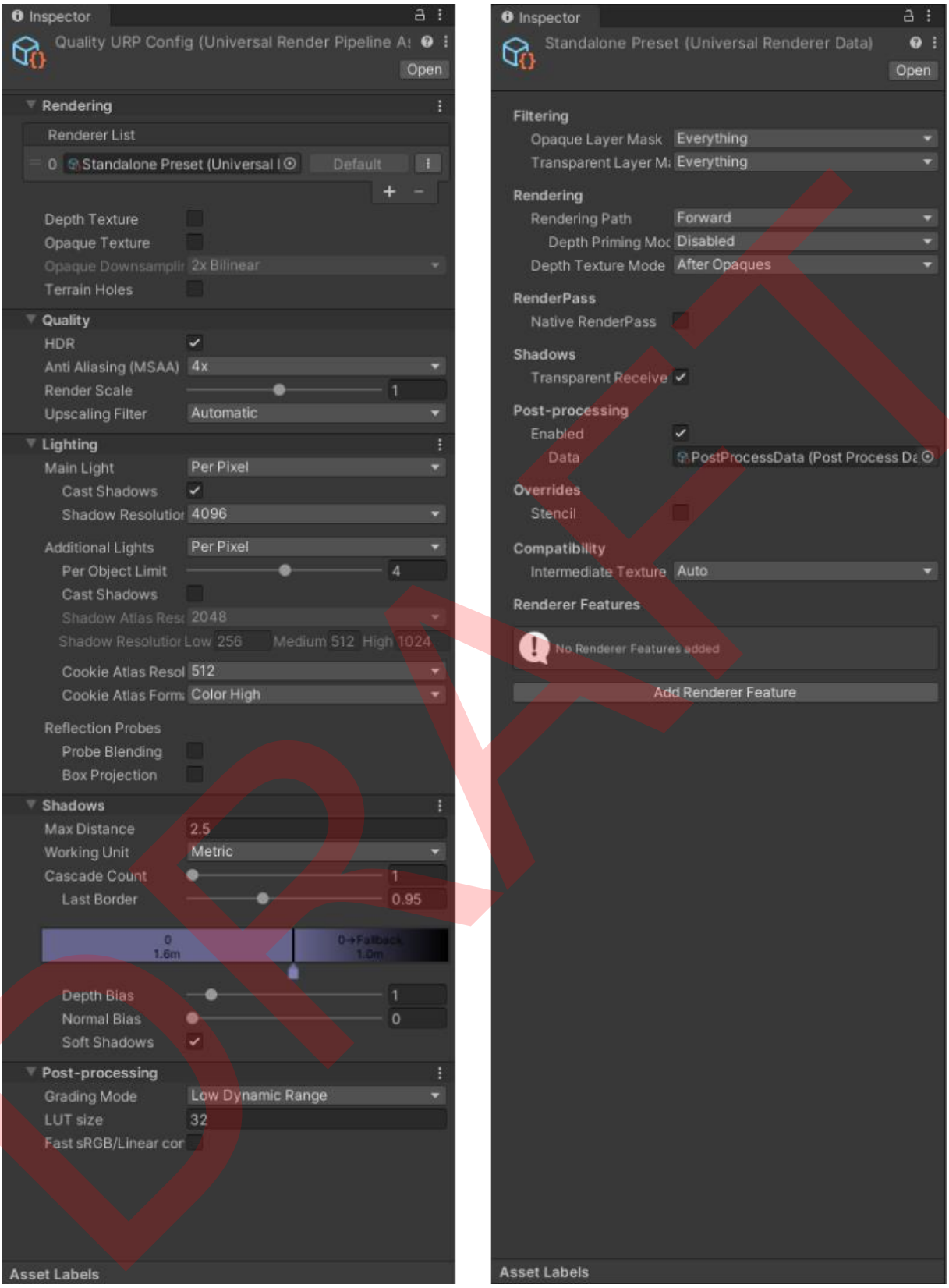

Figure 3.4.3.1: Universal Render Pipeline configuration settings.

3.4.3.1. Enhanced accessibility in text information

The virtual exhibition provides an improved level of accessibility regarding the texts that are associated with the artefacts. We applied accessibility features during the experience of reading the relevant

information of any exhibit through the adjustable UI. More specifically, we used the *BDKCreate Accessibility: Text resizing* tool that is available through *Unity Asset Store* (Unity Asset Store, 2024a). This asset allows users to resize the text of UI elements for their own comfort. It is a four step lightweight solution to add in this key accessibility feature. The overview of the four step process, is the following:

1. set up a *Unity UI Tex*t in scene,
2. enter minimum and maximum percentage of current text size (***Fig. 3.4.3.1.1***, ***Fig. 3.4.3.1.2***),
3. hit add all button, and
4. add in a UI control for the player to use (e.g. a slider) (***Fig. 3.4.3.1.3***).

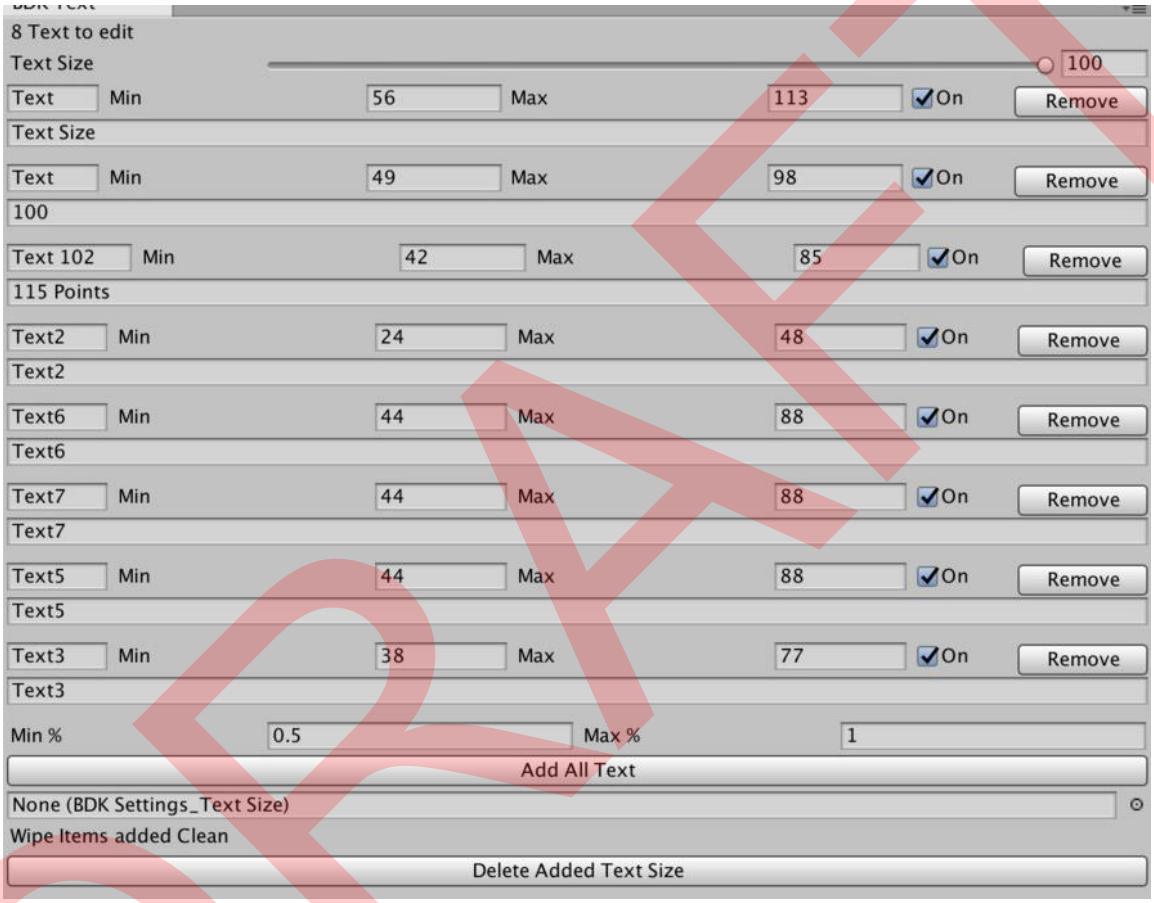

Figure 3.4.3.1.1: Setting the min/max percentages of the texts.

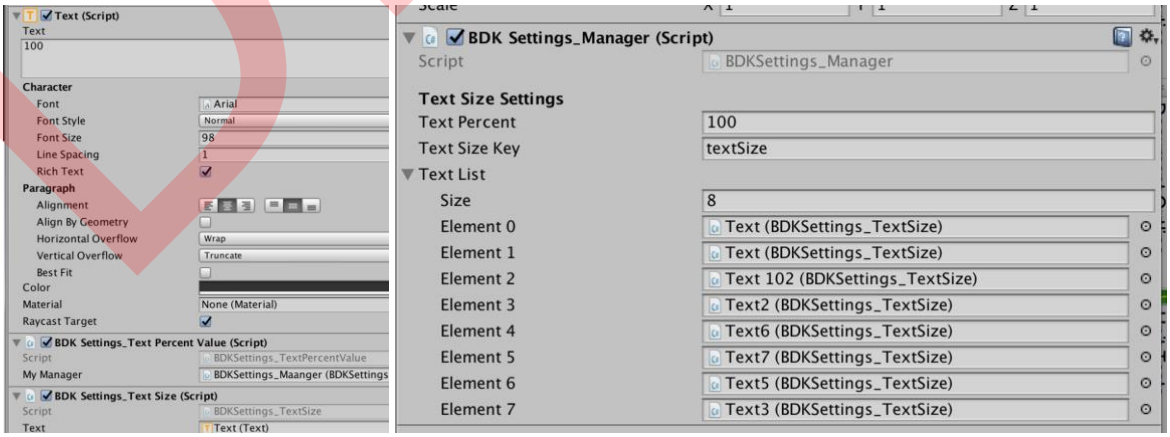

Figure 3.4.3.1.2: Further setting with the accessibility text resizing manager.

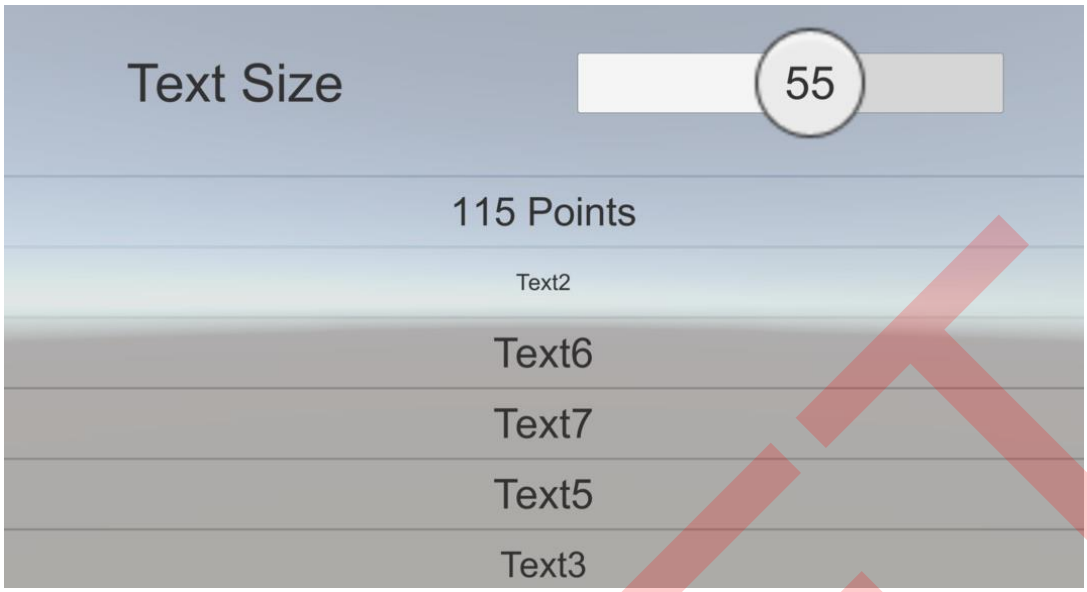

Figure 3.4.3.1.3: A slider UI for the adjustment of the accessibility text resizing.

We set the size of the text in specific points and we also set a minimum and a maximum percentage. The user can adjust the text in any container that the tool is being applied through a relevant UI, such as a slider. Thus, the text can be scaled up and down, according to the user's needs.

3.4.3.2. Enhanced accessibility through text-to-speech

In our effort to maximise the level of accessibility in the virtual exhibition space we have included an additional layer for the representation of the text information that is relevant to the artefacts. More specifically, we have included the possibility of announcing the descriptions of the exhibits through the functionality of text-to-speech (TTS). Though a C# script in *Unity Editor* we can assign specific texts to digital narrators. When the users trigger the interaction by selecting a button in a UI they can hear the full text. In the figure below (***Fig. 3.4.3.2.1***) the text-to-speech works when the user presses the key button "S".

```
using UnityEngine;
using SpeechLib;

Unity Script | 0 references
public class DontSprayIt : MonoBehaviour
{
    SpVoice voice = new SpVoice();

    Unity Message | 0 references
    void Update()
    {
        if (Input.GetKeyDown(KeyCode.S))
        {
            voice.Speak("You want a little piiie?", SpeechVoiceSpeakFlags.SVSFlagsAsync | SpeechVoiceSpeakFlags.SVSFPurgeBeforeSpeak);
        }
    }
}
```

Figure 3.4.3.2.1: The text-to-speech C# script in short for enhanced accessibility.

What is mainly needed is to include the latest version of the *Microsoft Speech Object Library* through the *Reference Manager* (***Fig. 3.4.3.2.2***). The enhanced accessibility through text-to-speech will be very useful for those users who have sight issues.

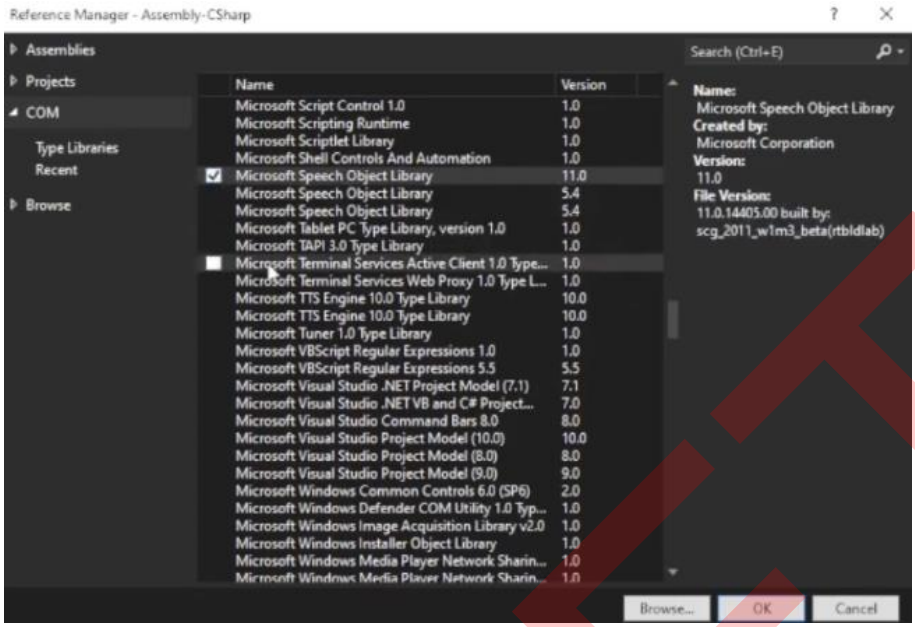

Figure 3.4.3.2.2: Adding the *Microsoft Speech Object Library*.

3.4.3.3. Ambient and specific sounds

In the first edition of the virtual museum for the MuseIT project we have included 3 (three) levels of sounds according to the position of the user. More specifically, we have included:

- The **ambient sound**: This sound is continuously playing during the navigation of the user in any non-thematic area of the virtual museum. This happens when the user does not trigger any of the thematic area colliders. Otherwise, it stops playing.
- The **thematic area sound**: This sound is triggered when the user is getting into any specific thematic area and it plays in loop continuously, as the user stays in this area. Its volume drops to zero when the user gets into and stays in any artefact area. The thematic area sound stops when the user exits from this trigger-collider. Then, the ambient sound starts playing again.
- The **artefact sound**: This sound is available only when the user is in front of any artefact and stays in its trigger collider. It is playing continuously in a loop. When the user leaves from an artefact, this sound stops playing. Then, the thematic area sound maximises its volume.

We made use of the well documented and supported audio advancements that the *Unity3D* game-engine offers (***Fig. 3.4.3.3.1***).

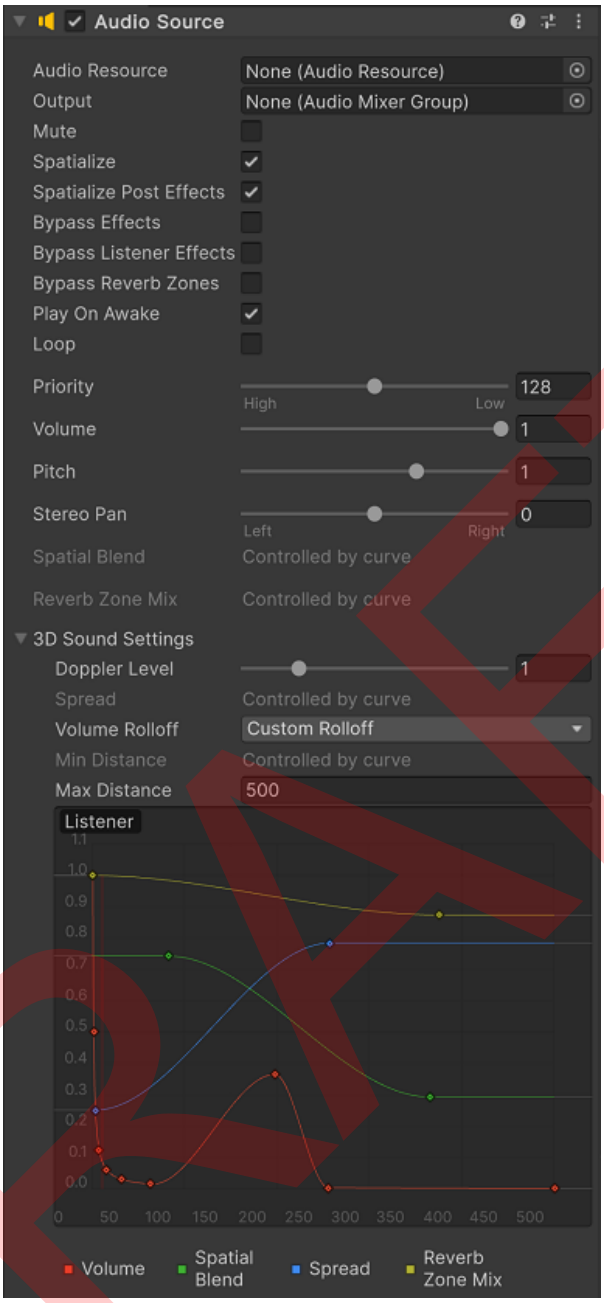

Fig. 3.4.3.3.1: The Audiosource panel in *Unity 3D* Properties.

For the second version of the virtual museum, it is planned to assign different sounds for each artefact, as well as different sounds for each thematic area, in conjunction with other partners.

3.4.3.4. Lights in the virtual exhibition

Regarding the lighting for the first edition of the virtual museum for the MuseIT project, we followed the recommended pipeline of *Unity* game engine (Fig. 3.4.3.4.1).

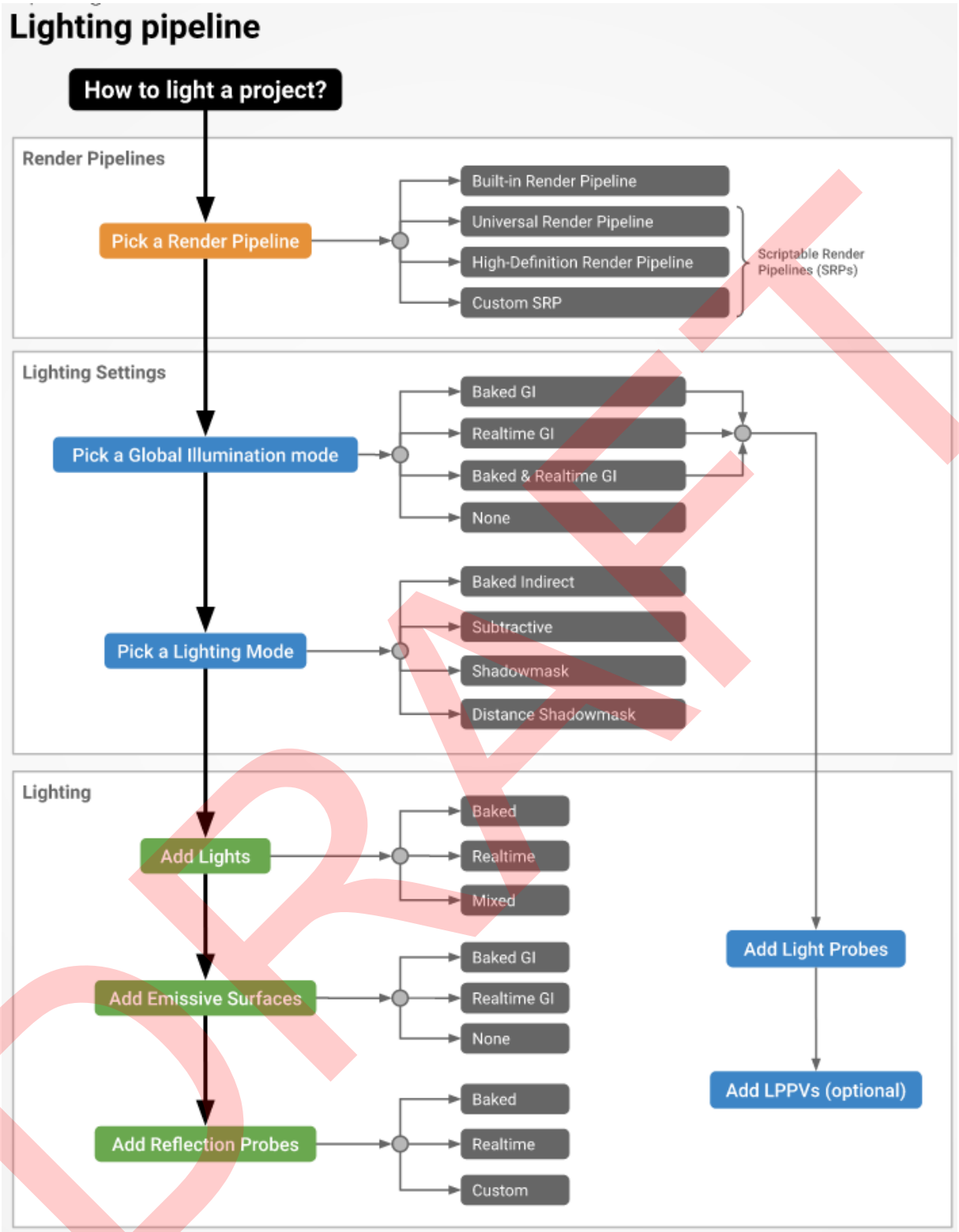

Figure 3.4.3.4.1: The recommended lighting pipeline that the first version of the virtual museum is based on (*Unity*, 2024).

3.4.4. Full immersive cultural heritage experience in VR

In this subsection some key points of the full immersive cultural heritage experience in VR are presented (***Fig. 3.4.4.1*** - ***Fig. 3.4.4.8***).

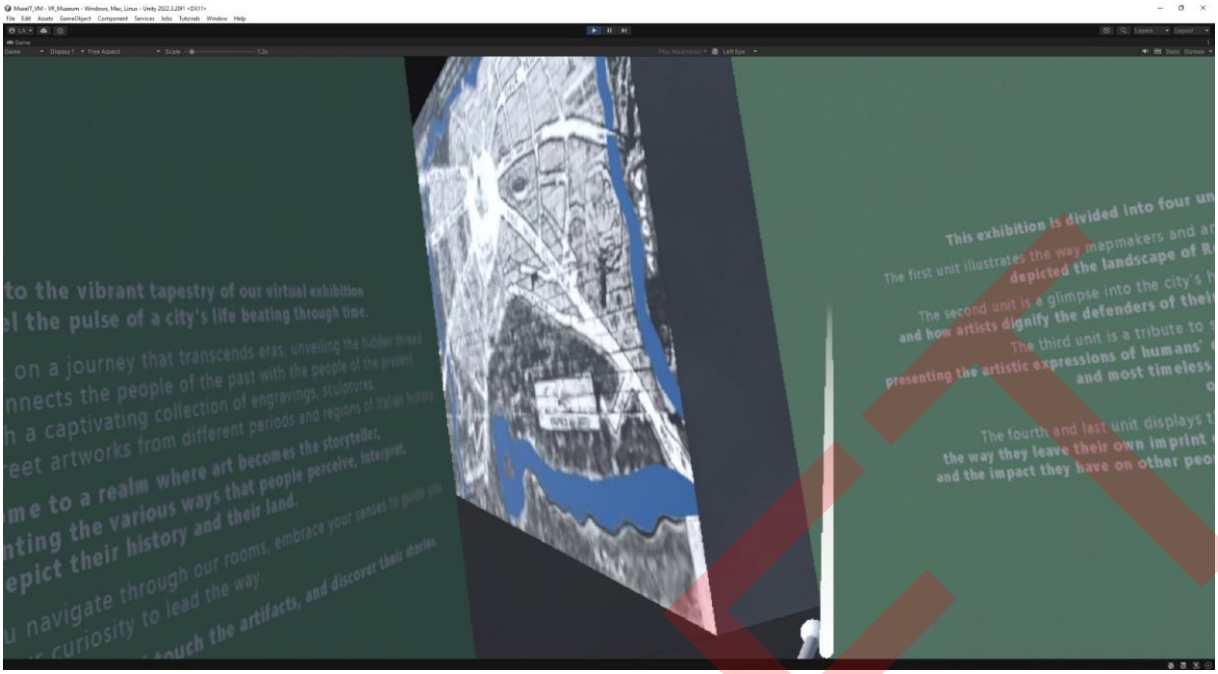

Figure 3.4.4.1: Starting point in the virtual museum.

Figure 3.4.4.2: The corridor that leads to the first thematic area of the virtual museum.

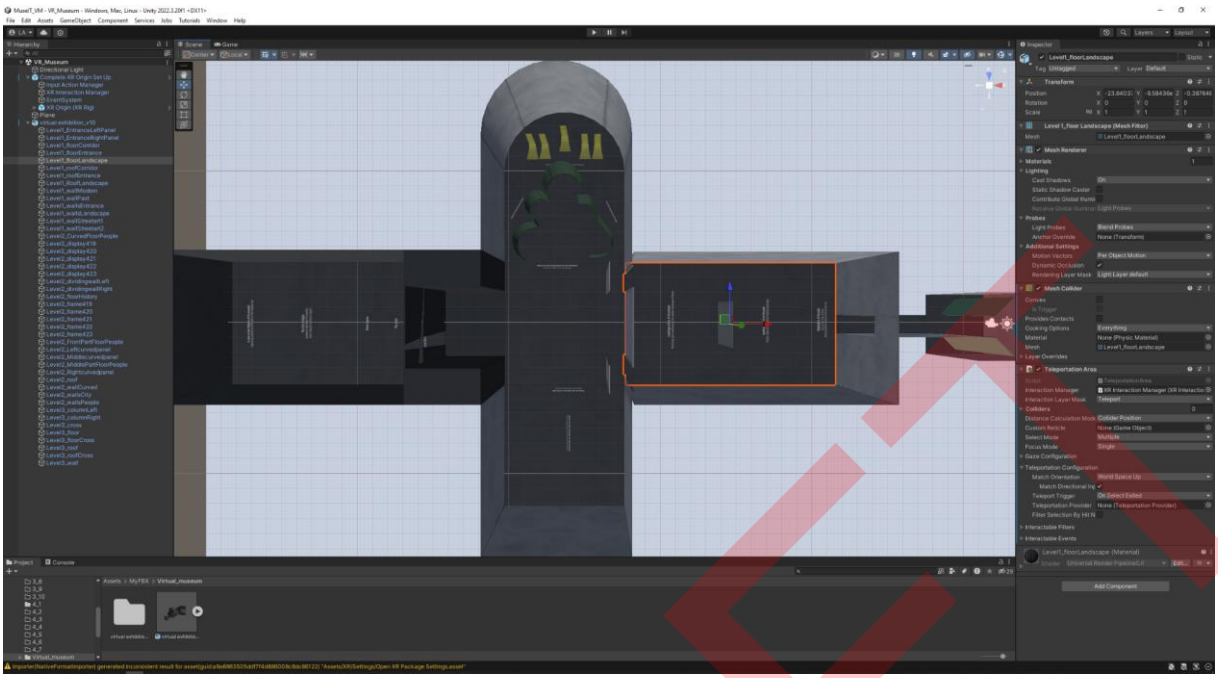

Figure 3.4.4.3: The whole virtual museum from top view in Unity editor.

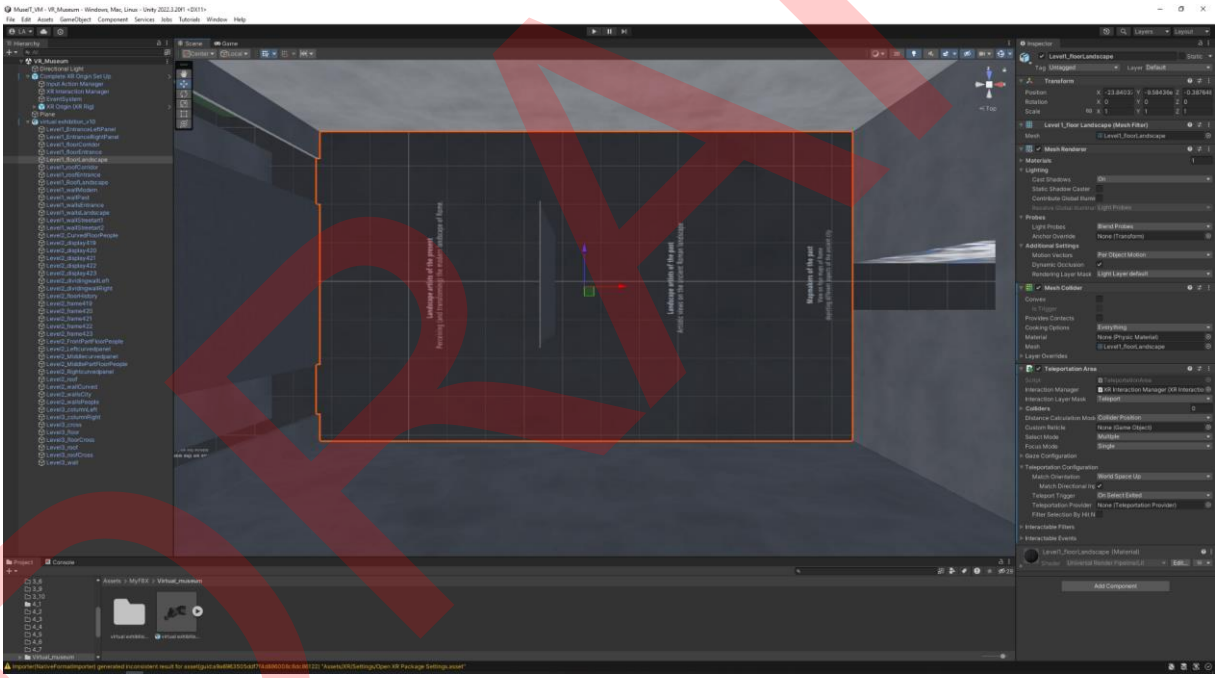

Figure 3.4.4.4: Setting up the teleportation area on the floor of the first thematic area.

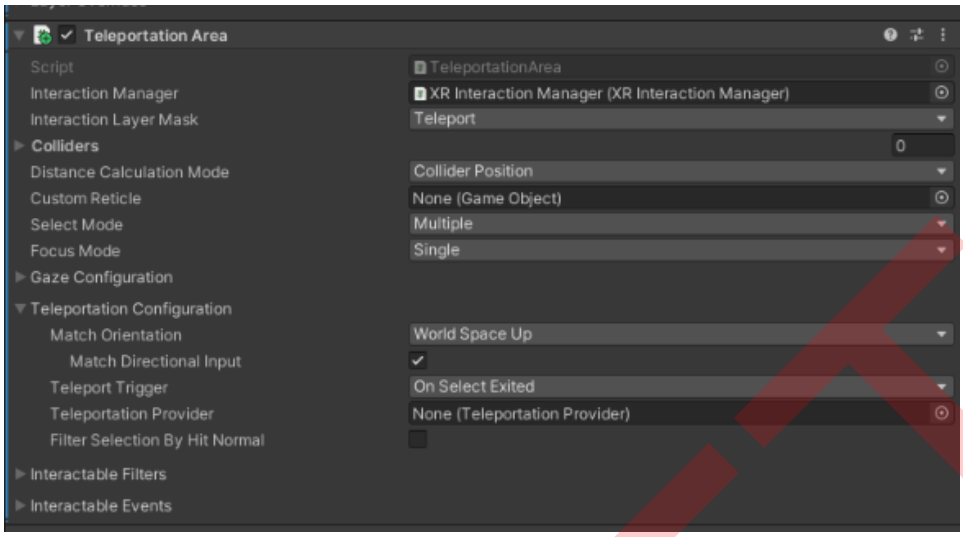

Figure 3.4.4.5: Setting the properties of the Teleportation Area Script in the Unity editor.

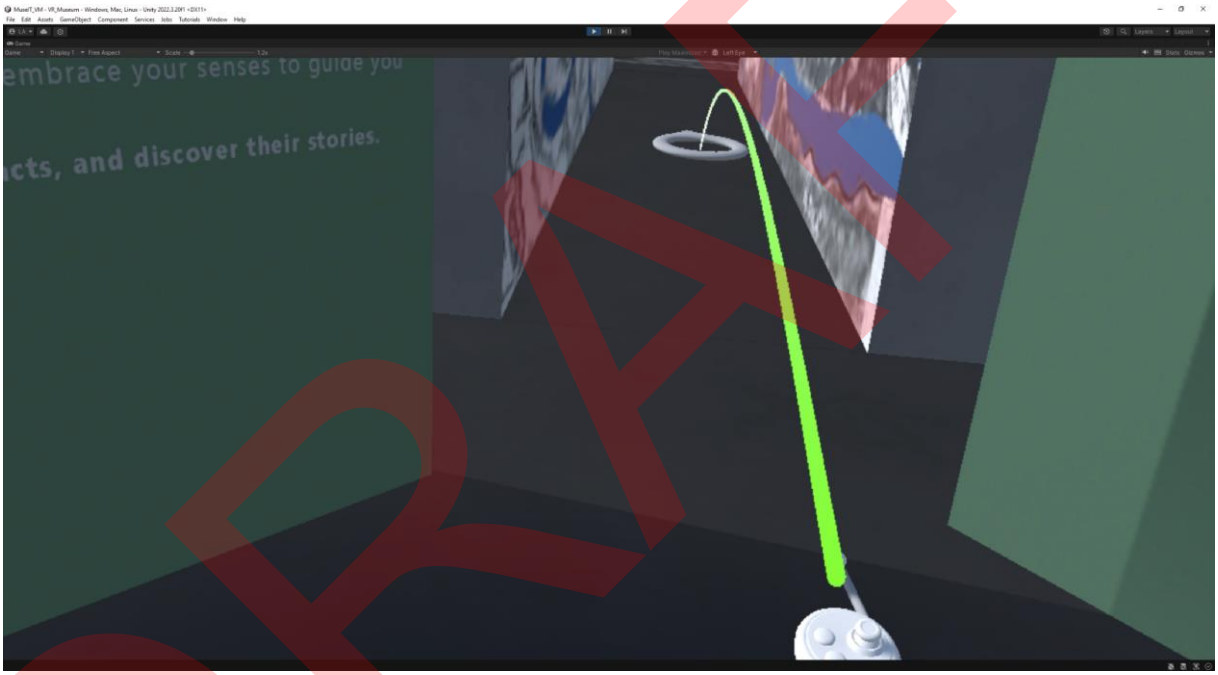

Figure 3.4.4.6: The user interacts with the floor through the jog of the right controller. More specifically the user selects the exact point that wants to teleport.

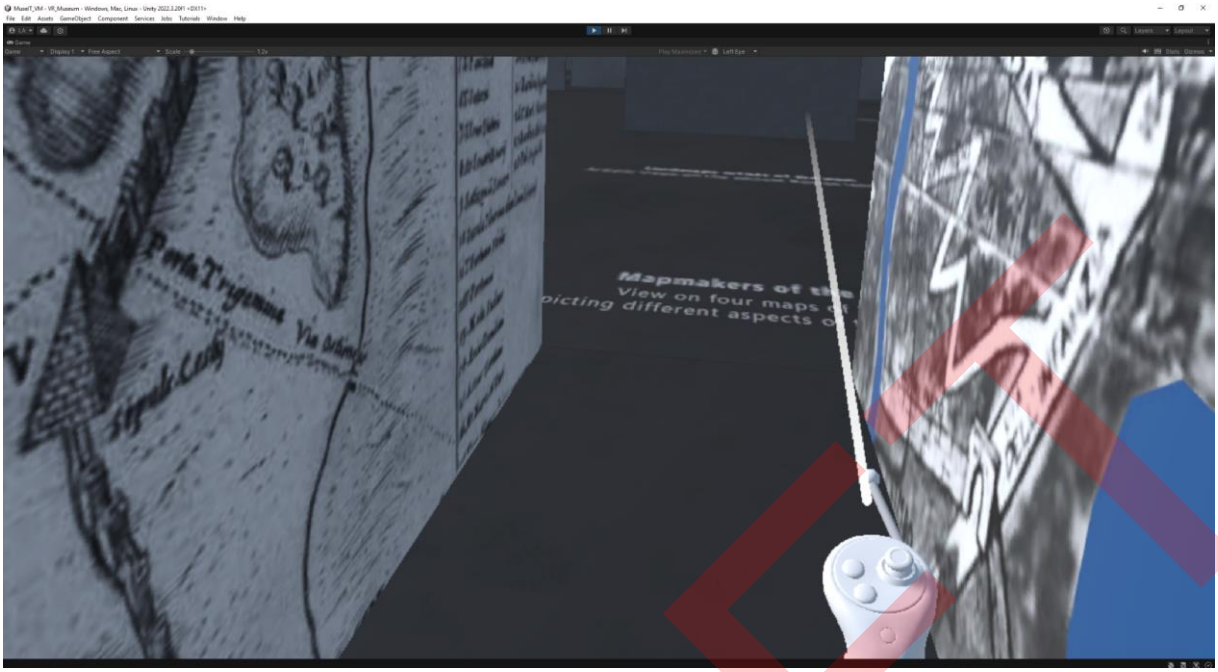

Figure 3.4.4.7: The user has been teleported on the exact point that was selected.

Figure 3.4.4.8: The user examines a specific 3D artefact on the third thematic area of the virtual museum.

3.5. Export and publish

In our effort to export and publish the standalone version for the virtual museum of the MuseIT project, we have to build it. To create a build for Windows, we have to go to Build Settings (menu: File > Build Settings). In the Platform list, we select Windows, then select Switch Platform (***Fig. 3.5.1***).

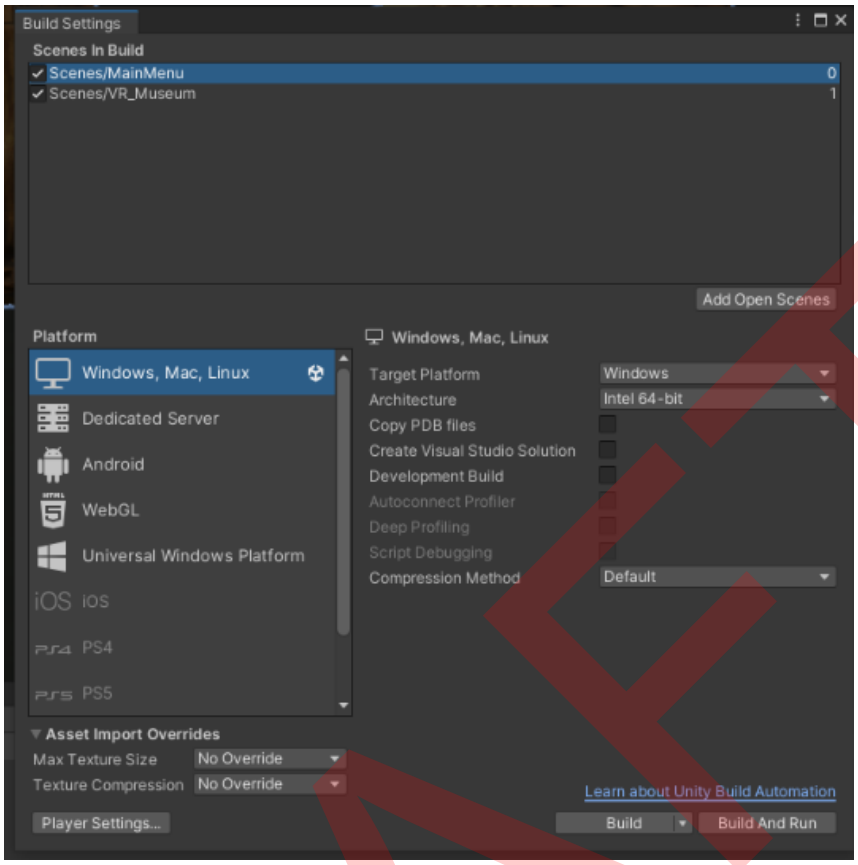

Figure 3.5.1: The build settings for the first edition of the virtual museum.

This procedure generates a set of folders and a relevant executable file. This edition is delivered to other research teams of the MuseIT project, as a standalone version, for further experiments and extensions, according to the technical description.

4. Summary

In conclusion, this deliverable presents a comprehensive framework for affective computing aimed at enhancing emotion recognition within the virtual exhibition of the MuseIT project. By leveraging data collected through a structured experiment, the framework will demonstrate the capability to accurately detect users' emotional responses as they engage with cultural heritage artefacts. The approach utilises both audio and visual stimuli to evoke a diverse range of emotions, contributing to a deeper understanding of user experiences within immersive environments. More experiments and more sophisticated algorithms for emotion recognition will be developed in the future and will be presented in subsequent deliverables.

Furthermore, the document highlights the significant progress made in the production phase of the MuseIT virtual museum, detailing the transition from conceptual design to the development of a fully immersive VR experience. Through careful planning and execution, the virtual museum serves as a unique experimental space for further research into multimodal and multisensory interactions, aligning with the project's broader objectives. More specifically, the first version of the virtual museum will be distributed to the research teams of the project to carry out further development and integration of multisensory interactions and experiments. Future experiments for the development of the Affective Computing Framework will be conducted using the aforementioned MuseIT virtual museum and future VR versions of the virtual museum will incorporate suitable adjustments based on these experiments.

Overall, this deliverable underscores the importance of integrating affective computing techniques into virtual exhibitions to enhance user engagement and understanding of cultural heritage artefacts. The implementation of the framework and the development of the MuseIT virtual museum mark significant milestones in the advancement of digital cultural heritage preservation and immersive museum experiences.

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Annex

Big-Five Factor Markers questionnaire

Instructions to participants: *The following phrases describe people's behaviour. Use the answers under each sentence to describe how accurately it describes you. Describe yourself as you are at the moment, not as you would like to be in the future. Describe yourself as you honestly perceive yourself in relation to other people of the same gender and about the same age. Indicate for each statement whether it is 1. Very Inaccurate, 2. Moderately Inaccurate, 3. Neither Accurate Nor Inaccurate, 4. Moderately Accurate, or 5. Very Accurate as a description of you.*

Note that the numbers in parentheses after each item indicate the scale on which that item is scored (i.e., of the five factors: (1) Extraversion, (2) Agreeableness, (3) Conscientiousness, (4) Emotional Stability, or (5) Intellect/Imagination) and its direction of scoring (+ or -). These numbers were not included in the actual survey questionnaire.

Phrase	Very Inaccurate	Moderately Inaccurate	Neither Accurate Nor Inaccurate	Moderately Accurate	Very Accurate	Scale
Am the life of the party.						(1+)
Feel little concern for others.						(2-)
Am always prepared.						(3+)
Get stressed out easily.						(4-)
Have a rich vocabulary.						(5+)
Don't talk a lot.						(1-)
Am interested in people.						(2+)
Leave my belongings around.						(3-)

Am relaxed most of the time.						(4+)
Have difficulty understanding abstract ideas.						(5-)
Feel comfortable around people.						(1+)
Insult people.						(2-)
Pay attention to details.						(3+)
Worry about things.						(4-)
Have a vivid imagination.						(5+)
Keep in the background.						(1-)
Sympathize with others' feelings.						(2+)

Make a mess of things.						(3-)
Seldom feel blue.						(4+)
Am not interested in abstract ideas.						(5-)
Start conversations.						(1+)
Am not interested in other people's problems.						(2-)
Get chores done right away.						(3+)
Am easily disturbed.						(4-)
Have excellent ideas.						(5+)
Have little to say.						(1-)

Have a soft heart.						(2+)
Often forget to put things back in their proper place.						(3-)
Get upset easily.						(4-)
Do not have a good imagination.						(5-)
Talk to a lot of different people at parties.						(1+)
Am not really interested in others.						(2-)
Like order.						(3+)
Change my mood a lot.						(4-)
Am quick to understand things.						(5+)

Don't like to draw attention to myself.						(1-)
Take time out for others.						(2+)
Shirk my duties.						(3-)
Have frequent mood swings.						(4-)
Use difficult words.						(5+)
Don't mind being the center of attention.						(1+)
Feel others' emotions.						(2+)
Follow a schedule.						(3+)
Get irritated easily.						(4-)

Spend time reflecting on things.						(5+)
Am quiet around strangers.						(1-)
Make people feel at ease.						(2+)
Am exacting in my work.						(3+)
Often feel blue.						(4-)
Am full of ideas.						(5+)

PANAS questionnaire

Instructions to participants: *This scale consists of a series of words and phrases that describe different feelings and emotions. Read each description carefully and choose the answer that suits you. Indicate to what extent you feel this way, right now, at this moment, using the scale menu of each description.*

The total score is calculated by finding the sum of the 10 positive items, and then the 10 negative items. Scores range from 10 – 50 for both sets of items. For the total positive score, a higher score indicates more of a positive affect. For the total negative score, a lower score indicates less of a negative affect. Positive and negative affect questions are indicated by (+) and (-) marks, respectively. These numbers were not included in the actual survey questionnaire.

Phrase/Word	Very slightly or not at all	A little	Moderately	Quite a bit	Extremely	Affect
Interested						+
Distressed						-
Excited						+
Upset						-
Strong						+
Guilty						-
Scared						-
Hostile						-
Enthusiastic						+

Proud						+
Irritable						-
Alert						+
Ashamed						-
Inspired						+
Nervous						-
Determined						+
Attentive						+
Jittery						-
Active						+

Afraid						-