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META-MUSEUM

*Moving **E**motions towards confidence in the **T**ransformative
Appropriation for a **M**eaningful **U**nderstanding of cultural
heritage: a neuro**S**cientific approach to **E**uropean **M**useums*

DELIVERABLE D2.3

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DISSEMINATION LEVEL PU - Public SEN - Sensitive

TYPE R - document, report DMP - Data Management Plan
 DATA - Data sets, microdata, etc DEM - Demonstrator, prototype
 OTHER

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DELIVERABLE REVIEW HISTORY

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0.2	22 May 2025	2 nd draft
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Final	30 May 2025	Submission to EC portal

LIST OF ABBREVIATIONS

ACRONYM	DESCRIPTION
AFz, AF3, AF4, AF7, AF8, Pz, P3, and P4	AFz : Anterior Frontal midline electrode AF3 : Anterior Frontal electrode 3 (left hemisphere) AF4 : Anterior Frontal electrode 4 (right hemisphere) AF7 : Anterior Frontal electrode 7 (left hemisphere) AF8 : Anterior Frontal electrode 8 (right hemisphere) Pz : Parietal midline electrode P3 : Parietal electrode 3 (left hemisphere) P4 : Parietal electrode 4 (right hemisphere)
AP	Antero-Posterior position
CH	Cultural Heritage
COP	Centre of pressure
EDA	Electrodermal activity
EEG	Electroencephalography
HVAC	Heating, Ventilation, and Air Conditioning.
Hz	Herz
GFP	Global Field Power
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GSR	Galvanic Skin Response
IAF	Individual Alpha Frequency
PANAS	Positive Affect and Negative Affect scale
SCL	Skin Conductance Level
TMt	TransforMeans theory
WP	Work Package

FRAMEWORK

1. Reference to WP and tasks as described in the DoA

WP2: Theoretical framework and T2.3 General assessment and interpretation Model

2. WP2 and T2.3 objectives as described in the Proposal

WP2 aims at providing a robust theoretical framework in designing, implementing and assessing the META-MUSEUM activities. Through a transdisciplinary perspective, it will deepen the perception of the transformative nature of CH and the empathic approach to make it understandable to citizens and increase their confidence.

D2.3 is related to T2.3: This task aims to: define indicators, metrics, components, data, which have to be collected during experimentations, and their interrelations; define an Assessment Model for experimentations, to validate them; define the Evaluation and Interpretation Matrix, crossing neurophysiological and cognitive components, in a holistic perspective. This process includes statistical analysis, qualitative analysis, sociological and psychological analysis, and content analysis.

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1 Introduction

The META-MUSEUM project aims to explore **cultural experiences through a neuropsychophysiological and cognitive lens**, focusing on emotional dynamics and the effectiveness of narrative solutions in fostering visitors' emotions, deeper understanding, and confidence. This project emphasises the **transformative potential of cultural heritage (CH)** and seeks to engage audiences in meaningful, empathic ways, ultimately enhancing public confidence in and connection to CH.

To achieve this, **robust evaluation mechanisms are needed to capture the multidimensional impact of the project**, from the emotional and cognitive responses of visitors to their behavioral and neurophysiological engagement. This **General Assessment and Interpretation Model is therefore not just a tool for measuring outcomes, but a critical framework for interpreting human interaction with the META-MUSEUM experience**. It allows the project's team to continuously evaluate how well the system delivers on its promise of inclusive, interactive, and intelligent cultural exploration, while also enabling evidence-based design decisions throughout the development lifecycle.

The model encompasses a wide range of domains to reflect the complexity and richness of user experiences in the META-MUSEUM, such as **neurophysiological aspects, psychometric scales, emotional, affective, and physiological metrics**. By integrating these dimensions, this document moves toward providing **a holistic understanding of how users perceive, interact with, and are affected by the META-MUSEUM experience**.

The Assessment and Interpretation Model is strategically aligned with the overarching objectives of META-MUSEUM, serving as both a diagnostic and developmental instrument. It supports the project's goals in several keyways: First, **it informs iterative improvements** based on user data and real-time feedback by applying validated methods for data collection and analysis to support robust conclusions. Second, **it facilitates the convergence of qualitative and quantitative insights**, ensuring that the emotional, cognitive, and social dimensions of experience are equally valued. Third, **it provides clear metrics and indicators to evaluate the effectiveness of proposed tools** in enhancing museum engagement. Ultimately, this model serves not only as a measurement framework but also as **a guide for interpretation**, considering user needs and content accessibility, to improve confidence in users.

It is important to note that **although the current Assessment and Interpretation Model represents a complete and cohesive framework, many of the project's protocols, assessment procedures, and interventions are still under development at the time of this report's submission**.

2 Theoretical Framework

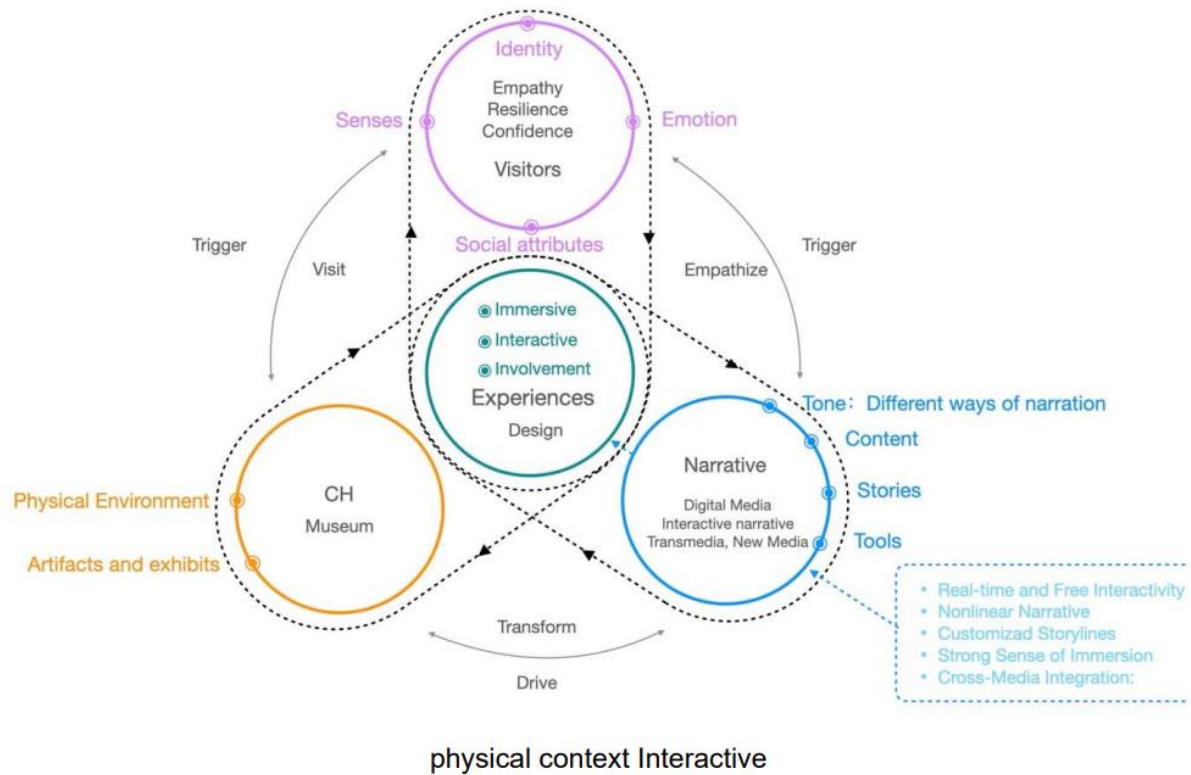
The META-MUSEUM project explores how engagement with CH affects individuals on neurological, psychological, and social levels. It specifically investigates whether interactions with **cultural artefacts and narratives can cultivate empathy, boost confidence and self-confidence, and strengthen resilience**. A key objective is to determine which methods of cultural communication can effectively deliver these outcomes across varied demographic groups. This study is grounded **in the TransforMeans Theory (Tmt)**, which outlines a model explaining how encounters with cultural heritage may lead to transformative processes. This framework, introduced by Minucciani et al. (2024), will continue to evolve throughout the project's duration.

According to Tmt, **CH can support both personal and collective development**; its **transformative effect** is most apparent when individuals connect with cultural exhibits on an emotional level, interpreting them through the lens of their personal histories, personalities, memories, and preferences (Benente & Minucciani, 2022). These emotionally rich interactions are often more enduring and influential (Varutti, 2023; Whitcomb, 2015), stimulating reflection and curiosity. This process can lead to increased self-awareness, a stronger sense of identity and belonging, and the growth of empathy by enabling individuals to relate to the lives and experiences of others, while appreciating humanity's rich diversity.

The transformative aspect of CH also surfaces in how visitors perceive resilience within cultural narratives. By recognizing that cultural objects and meanings are continuously reinterpreted, individuals may begin to view cultural heritage as inherently adaptable (Minucciani et al., 2024). This insight can inspire viewers to see **change as natural and resilience as the ability to adapt, encouraging them to face contemporary difficulties with greater confidence and to perceive obstacles as potential opportunities for development**. Tmt frames CH as an ongoing dialogue between historical traces and present-day interpretations, illustrating it as a representation of resilience in a constantly evolving, interconnected world.

Tmt's practical implications involve the design of heritage experiences that actively foster transformation in diverse audiences. The theory proposes a structured approach to create such experiences, emphasizing the dynamic interplay between the visitor and three main components: the cultural objects themselves, the surrounding physical space, and the narrative or storytelling element (Minucciani et al., 2024) (see Figure 1). **Visitors are seen as active participants in a cyclical process where their emotional and cognitive responses interact with these elements**. The cultural content and environments act as stimuli that provoke thought and emotion, situated within a communicative atmosphere (Varutti, 2023) and enhanced by immersive or interactive design features and storytelling media. Each component plays an important role in shaping interpretation (Benente & Minucciani, 2022). The spatial environment sets an emotional stage, while narrative methods, such as cultural storytelling, help evoke emotional engagement and empathetic understanding (Bonacini & Marangon, 2020)

Figure 1. Key components in designing transformative cultural heritage experiences



Note: Interdependent relationships are shown between the visitor and the key design components: the cultural artefacts, the experiential design and the narrative experience. From Deliverable D2.1 TransforMEANS Theory. First Version (p. 25), by V. Minucciani, M. Benente, H. Zipsane, & Y. Sun, 2024. Copyright (2024) by META-MUSEUM. Reprinted with permission.

3 META-MUSEUM Assessment Model

3.1 General structure of the META-MUSEUM Assessment Model

Although the literature includes several assessment frameworks for various disciplines and research projects, the unique and innovative nature of the META-MUSEUM project requires the development of a tailored assessment model based on the TMT, the project's specific objectives and assumptions, and the diverse data collection and analysis activities to be carried out by the consortium across different WPs and tasks.

The META-MUSEUM project aims to investigate **how CH can serve as a catalyst for psychosocial transformation, enhancing empathy, confidence, and resilience across diverse audience groups**. This goal is grounded in the TMT, which postulates that emotionally meaningful encounters with cultural narratives and artefacts can foster individual and collective confidence by deepening self-awareness, stimulating curiosity, and reinforcing a sense of belonging. To operationalize this vision, **an integrated assessment model framework (Table 1) is provided that captures what is to be assessed, when, how, and by whom**, while reflecting the structure and work packages (WPs) of the project.

- **Transformative Focus (What is Assessed):** Rather than focusing solely on knowledge acquisition or content recall, the assessment framework emphasizes specific **psychosocial outcomes: foremost among these is increased confidence, along with emotional engagement, the development of empathy, and resilience, cultivated through meaningful cultural narratives**. These **outcomes reflect the theoretical claims of TMT**, which asserts that individuals interpret CH through the lens of their personal histories, emotional states, and lived experiences. **The Assessment Model also explores how participants relate to the adaptability of CH itself**, understanding that cultural narratives are not fixed but continuously reinterpreted, which in turn encourages them to embrace adaptability in their own lives. **This holistic approach supports the project's aim of measuring not only cognitive engagement but emotional and identity-based transformation**.
- **Engagement Windows (When Assessment Occurs):** To capture the temporal evolution of transformation, assessments are conducted across multiple phases:
 - Pre-engagement assessments capture baseline emotional and psychological traits, providing a reference point for later comparisons.
 - During engagement, real-time monitoring captures participants' physiological and cognitive responses to CH stimuli using wearable technologies.
 - Post-engagement (short-term) assessments examine immediate shifts in perception, self-report measures, and reflective outputs.
 - Post-engagement (long-term) follow-ups explore the sustainability of transformation, particularly in confidence and resilience.

This staged approach aligns with the implementation timeline across experimental Pilots in WPs 6,7, and 8.

- **Methods of Insight (How Assessment is Conducted):** The project employs a mixed-methods approach combining qualitative and quantitative tools:
 - Quantitative methods include psychometric surveys, cognitive-behavioral assessments, and physiological monitoring tools such as EEG (electroencephalography) headsets and electrodermal activity sensors (WP5).

These are used to track emotional responses and cognitive workload during CH engagement.

- Qualitative methods encompass interviews, narrative reflections, and creative expressions. These methods uncover the nuanced, subjective aspects of emotional engagement and identity exploration (WP2, WP4).
- Data from all methods will be curated within an Open Database developed in WP3, ensuring standardization, transparency, and accessibility for cross-analysis.
- **Transformative Governance (Who Oversees the Assessment):** Oversight of the assessment process is distributed across the project's interdisciplinary structure:
 - WP2 serves as the theoretical and methodological anchor, responsible for defining conceptual categories, audience segmentation, and the iterative development of the TMt framework.
 - WP5 provides scientific expertise in conducting physiological monitoring and ensuring data validity through lab-based experiments.
 - Piloting WPs (WP6, WP7, WP8) oversee real-world implementation across museums, hospitals, and public outdoor events, respectively, ensuring context-sensitive and ethical application of assessment tools.
- **Quality Assurance and Trustworthiness (Validity and Reliability of Measurements):** Ensuring methodological rigor, ethical integrity, and confidence in the findings is a core priority. Several potential challenges are anticipated in both data collection and analysis, and in summary, the following mitigation strategies have been established:
 - Data variability due to differing cultural, cognitive, or emotional baselines across diverse audiences will be addressed through careful audience segmentation (WP2) and the use of control and comparative groups in experimental phases.
 - The challenge of accurately and consistently capturing the construct or phenomenon being studied (e.g., well-being, confidence) will be mitigated using validated psychometric scales.
 - Technological limitations in wearable devices (e.g., signal noise, usability issues) will be mitigated through pilot testing and iterative calibration of equipment in WP5.
 - Subjectivity in qualitative interpretation will be handled through triangulation of data sources (e.g., physiological, narrative, and psychometric data) and interdisciplinary coder validation across teams.
 - Ethical concerns, especially around biometric monitoring, are addressed via informed consent, transparent communication with participants, and adherence to GDPR and research ethics protocols, overseen by the project's ethics board.
 - Data security and integrity will be guaranteed by the design of the Open Database (WP3), using structured metadata, anonymization protocols, and controlled access levels.
 - **More detailed information on quality assurance of the assessments are provided in Section 3.6**

Table 1. Integrated Assessment Model Framework

Component	Focus and Implementation
Transformative Focus <i>(What is assessed)</i>	Emotional, cognitive, and psychosocial outcomes: empathy, confidence, resilience - Interpretation of cultural heritage through personal histories, identities, and memories - Perception of adaptability and resilience in cultural narratives (WP2, WP4, WP5)
Engagement Windows <i>(When it is assessed)</i>	Pre-engagement: Baseline psychometric and demographic profiling (WP2, WP5) During engagement: monitoring via wearable sensors (WP5–WP8) Post-engagement: Immediate and follow-up qualitative/quantitative assessment (WP6–WP7)
Methods of Insight <i>(How it is assessed)</i>	Quantitative: EEG, GSR, heart rate; validated psychometric tools (WP5) Qualitative: Interviews, reflective narratives, open-ended questions in surveys (WP2, WP4) Data stored and managed via Open Database (WP3)
Transformative Governance <i>(Who oversees the assessments)</i>	WP2: Theoretical coordination, sample design, questionnaires design, and TMt refinement WP5: Technical and experimental monitoring supervision WP6–8: Contextual assessment deployment in pilots (museums, hospitals, public events) Ethical oversight integrated
Quality Assurance and Trustworthiness	Audience segmentation and comparative groups to manage data variability (WP2) Use of validated psychometric scales Pilot-testing of devices and calibration for reliability (WP5) Triangulation of qualitative and quantitative data; interdisciplinary coder checks Ethical safeguards (e.g., informed consent, anonymization, GDPR compliance) Secure, structured Open Database with metadata and access protocols (WP3)

3.2 Definition of Measurements- Key Indicators and Parameters

3.2.1 Neurophysiological and Psychometric Assessment

Given that the parameters will be measured in relation to the position users will be in within the museums, the assessment will be carried out as follows:

The T5.1 task, led by UNIROMA 1, consists of the development of a protocol for the Psychometric and Physiological Quantitative Assessment of Well-being and Confidence. The aim is to establish a standardised protocol for assessing confidence and well-being across the project, utilising validated psychometric scales along with physiological indices. Physiological data will be gathered using a portable Electroencephalography (EEG) headset and biometric electrodes for measuring electrodermal activity. Together, these devices will capture **neurometrics related to cognitive workload, attention, and emotional engagement**, enabling a comprehensive assessment of subjective well-being and confidence. For the T7.1, led by UNIROMA 1, the psychometric and neurophysiological measures identified in T5.1 will be adapted to clinical settings and population according to the scientific literature.

Further, in T5.3 & T5.4 tasks, led by STICHTING VU, will also work towards employing reliable psychometric scales and physiological indices in a laboratory setting to address the transformative potential of CH. Physiological measures will be combining an EEG portable headset and bracelets measuring **heart rate and electrodermal activity, for assessing neurometrics, i. e. indices related to cognitive workload, attention, emotional engagement, and postural indices measuring forces to derive the centre of pressure**

3.2.1.1 Neurometrics Acquisition and Processing

EEG data will be acquired using a Mindtooth Touch EEG headset with water electrodes (saltwater sponge and passive Ag/AgCl electrodes) (Mindtooth) (Sciaraffa et al., 2022). Electrodes will be positioned according to the International 10-10 System at the following locations: AFz, AF3, AF4, AF7, AF8, Pz, P3, and P4 (Oostenveld & Praamstra, 2001). Moreover, a reference and a ground electrode will be placed on mastoids. The device has been validated and is capable of recording EEG signals with high accuracy (Sciaraffa et al., 2022). The sampling frequency will be 125 Hz. A 50 Hz notch filter will be applied to remove mainline power interference. The EEG signal will be band-pass filtered (high-pass filter cut-off frequency: 2 Hz; low-pass filter cut-off frequency: 40 Hz). The artefacts removal will follow the protocol used by Giorgi et al. (2024). The reconstructed EEG signal will be segmented into 1-second epochs with 0.5-second overlap to mitigate boundary effects. Additional artefact detection criteria, based on signal amplitude and trend (Delorme & Makeig, 2004; Vozzi et al., 2021), will be applied to exclude segments still affected by artefacts.

For the **Frequency Band Analysis**, Global Field Power (GFP) will be computed for the alpha and theta frequency bands. The alpha band will be defined as [IAF-2, IAF+2] and the theta band as [IAF-6, IAF-2], where Individual Alpha Frequency (IAF) will be estimated from one minute of eyes-closed data recorded before the experiment (Klimesch 1999).

Variables:

- **Approach-Withdrawal index:** This index will be extracted from the Frontal Alpha Asymmetry and calculated using the formula: $GFP_{right}/n - GFP_{left}/m$ where GFP_{right} and GFP_{left} represents the GFP values calculated among right (AF4, AF8) and left (AF3, AF7) electrodes, respectively, in the alpha band, and where n is the number of frontal right electrodes and m is the number of frontal left electrodes. Positive values indicate an approach/interest tendency, while negative values suggest a withdrawal tendency (Davidson et al., 1990; Cartocci et al., 2018).
- **Cognitive Effort Index:** Derived from the GFP in the theta band over all the frontal electrodes (AFz, AF3, AF4, AF7, AF8). Increased theta values are indicative of higher cognitive effort (Cartocci et al., 2021; Wisniewski et al., 2015).

Figure 2. Close-up view of the Mindtooth Touch EEG headset device used for recording EEG data (Source: <https://www.mindtooth.com/>)



3.2.1.2 Physiological Signals Acquisition and Processing

Galvanic Skin Response (GSR)

Equipment: Electrodermal activity (EDA) will be recorded with a Shimmer 3 GSR+ device (Shimmer Sensing, Ireland) with a sampling rate of 64 Hz, applied to the nondominant hand of the subject. The constant voltage method (0.5 V) will be used for GSR acquisition. Electrodes will be placed on the palmar side of the middle phalanges of the second finger of the nondominant hand, following established procedures (Boucsein et al., 2012).

Variable: the tonic component of the EDA signal, known as **Skin Conductance Level (SCL)**, will be estimated using LEDA lab software (Benedek & Kaernbach 2010). SCL represents the slow-changing component of the EDA signal and is related to arousal and stress levels (Ronca et al., 2023).

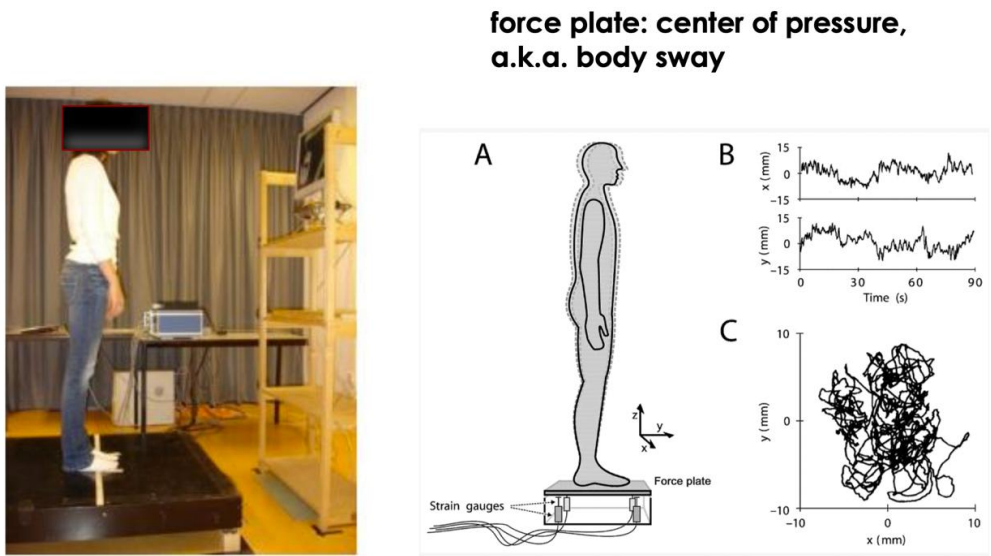
Figure 3. Close-up view of the Shimmer 3 GSR+ device used for recording Electrodermal Activity (EDA) (Source: <https://shimmersensing.com/>).



3.2.1.3 Postural Indices

Equipment: A force plate measuring forces at 100Hz. From the forces the centre of pressure (COP) can be derived, which is related to the overall position (e.g., displacement, lean, direction) of the body; see Figure 4.

Figure 4. Example of the lab setting



Note: *Experimental Setting: The figure shows an example of the lab setting; in this example a subject is standing quietly on a force plate (black bow) while looking at a visual stimulus; in this case a snake. To the right we see example COP profiles, which we analyse using time-series methods. In the actual experiment many parameters need to be set, such as the size of the display; the distance between subject and display; the type of visual stimuli; their duration, the instructions, etc.*

Emotional Estimation Variable: the literature and the work performed at the VU Amsterdam (Lelard et al., 2018; Stins et al. 2022; Stins & Beek, 2007) has identified several markers in the COP analysis that are related to emotion, attention, cognitive workload, etc. An important marker is **sway variability**; there is evidence that situations that are highly attentional-captivating lead to a (temporary) reduction in sway variability. This is sometimes called postural ‘freeze’ and related to awareness of the environment. Another marker is the **mean position of the COP in the anterior-posterior direction**. There is evidence that unpleasant items lead to a small spontaneous (unconscious) backward lean. This is objectively visible in the mean Antero-Posterior (AP)-position during a time interval (e.g., stimulus exposure). The converse pattern, i.e., spontaneous ‘approach’ (forward lean) is less robust in literature (Stins & Beek, 2007).

3.2.1.4 Positioning

As already mentioned in D3.1, two different positioning approaches will be considered in this research project: ultra-wideband (UWB) for indoor localization and low-cost GNSS portable devices for outdoor positioning. For **indoor** tracking applications (in WP6), positioning accuracy must be maintained within ± 0.1 meters. This precision level ensures reliable visitor movement analysis and spatial correlation with emotional responses and enables interactive experiences, such as guiding visitors through exhibits or locating specific artifacts with ease.

Within the META-MUSEUM project, **outdoor** (in WP8) user positioning during community-related events will be achieved by leveraging the Global Navigation Satellite System (GNSS) sensors integrated into users’ smartphones. This approach enables a non-invasive and cost-effective method to gather geo-localization data, which is essential for analyzing how participants interact with the

physical environment and respond to specific stimuli introduced during the events. The primary objective of this positioning activity is not to obtain high-precision localization data, but rather to gain a sufficiently accurate understanding of user movements across different zones or areas of interest. Metric-level accuracy, typically achievable with standard GNSS-enabled smartphones under open-sky conditions, is deemed adequate for the intended analysis. Such precision will allow the project team to reconstruct general movement patterns, identify areas with higher user engagement, and correlate spatial behavior with the distribution and nature of the stimuli provided.

To ensure the reliability and usefulness of the collected positioning data, the GNSS performance of smartphones will be evaluated through a series of validation tests. These tests will be carried out in controlled outdoor environments that reflect the conditions expected during the actual events. **The goal is to assess the average positioning accuracy, detect potential sources of error (e.g., urban canyons, signal obstructions), and confirm that the chosen approach meets the needs of the project in terms of spatial resolution and data consistency.** This methodology allows the project to scale participation without the need for specialized hardware, relying instead on ubiquitous mobile technology already available to most users. It also facilitates integration with custom mobile applications or data collection platforms that may be used during the events to enrich the geospatial dataset with contextual or user-generated information.

Relation with **neurometrics acquisition** will be achieved through a synchronization of Mindtooth software (running for Shimmer device too), already tested in previous experimentations carried out by POLITO.

3.2.1.5 Questionnaires

Selected validated scales are reported below and will be used across tasks of WP5, WP6 and WP7 based on the defined protocols.

Confidence: The General Confidence Scale proposed by Keller et al., (2011) will be used in this project. This scale refers to confidence towards the future concerning the characteristics of present-day society, but can be easily adapted to also assess the confidence in present-day society compared to the characteristics of past societies and their CH.

Well-being: The General Wellbeing Questionnaire (Thomson & Chatterjee, 2014) will be used to assess participants' experiences. The full version of the scale consists of 12 items, rated based on the extent of agreement with each statement, from 1 (None of the time) to 5 (All of the time). Among the items, the scale assesses confidence and health, which are key aspects for the present project.

Affective State: To assess how CH may influence positive and negative effects (that are two dominant and relatively independent dimensions), the Positive Affect and Negative Affect scale (PANAS) will be used. Among different mood scales developed to measure these factors, PANAS shows a good level of validity and reliability (Watson et al., 1988). It consists of two 10-item mood scales that comprise the Positive and Negative Affect assessment. It includes an assessment of these domains in terms of trait and in terms of a state that can be influenced by the aesthetic experience.

Aesthetic Experience: Current scientific literature lacks a robust, psychometrically validated scale for assessing aesthetic experience, specifically in terms of beauty perception, that can differentiate between subjective, personal beauty and an objective, culturally influenced concept of beauty. Although various methods, such as Numeric Rating Scales or Visual Analogue Scales, have been proposed to address specific questions regarding the perception of beauty and aesthetic

attractiveness (Iosa et al., 2022), there remains a need for a reliable, validated instrument. Therefore, as part of WP5, we aim to develop and validate a comprehensive scale for aesthetic judgement, which could subsequently be applied in WP6 and WP7¹.

Customized Questionnaire for the Project: In each museum (Museo Egizio, MAC Barcelona, MuseoParc Alesia) the following measures will be collected:

- Data collected before the visit to the museum:
 - Demographic data: gender, age, education level, job status
 - Role of museums in respondents' life
 - Personality evaluation (Scale: Ten-Item Personality Inventory (TIPI)) (Gosling, et al., 2003); Measured personality traits: Extraversion, Agreeableness, Conscientiousness, Openness to Experiences, Emotional Stability)
- Data collected before and after the visit to the museum:
 - Confidence level, measured with the General Confidence Scale (see above)
 - Expectations of the visit to the museum (expected benefits and emotional response)
 - Self-assessed knowledge about the topic of an exhibition
- Data collected after the visit to the museum:
 - Evaluation of exhibition aesthetics (with the Beauty Assessment Scale, see above)
 - Well-being, with the General Wellbeing Questionnaire (see above)
 - Evaluation of Individualism & Collectivism, based on the Triandis & Gelfand (1998) 16-item scale.
 - Open-ended questions related to the museum experience and elicited reflection.

The interpretation of questionnaires will take into account various user characteristics, such as age, background, gender, and cultural habits as derived from the demographics section.

3.2.2 Assessment Framework for the Development and Implementation of the M⁴ System in Hybrid Cultural Events

This section provides an overview of the ongoing development and future implementation of the M⁴ System (WP8), an advanced real-time platform designed to monitor and respond to human emotional and physiological states during hybrid cultural events. Built upon the VILNIUS TECH real-time measurement system (validated at TRL 4), the M⁴ System is still under active development at the time of writing this deliverable, with all measurement tools currently being refined and integrated.

A foundational element in this process is **the definition of 58 distinct human emotional, affective, physiological, and urban space metrics, along with their interrelations**. These indicators have been used to develop and validate linear regression models for key emotional dimensions such as arousal, happiness, and valence. While some initial models and datasets have been shared, additional data, models, and detailed descriptions are planned for delivery in the near future to support the full realisation of M⁴.

The development of the M⁴ System involves the integration of diverse technologies, including **emotional, affective, and physiological sensors; recognition software; environmental equipment (such as HVAC systems); and wireless sensor networks**. This infrastructure will be

¹ The Beauty Assessment Scale (BAS, Iosa et al., under review) is a psychometrically scale assessing aesthetic experience suggested to be used in META-MUSEUM experiments. The scale includes 8 items loading on four general domains of beauty: Subjective, Objective, Emotional, Cognitive. More information will be given when this Scale is published and applied in the project.

technically integrated by a subcontracted team and paired with a real-time visualisation app to make emotional states perceptible during public events. Artificial intelligence will further enhance the system by optimising and adapting cultural content in response to participants' emotional reactions.

In preparation for deployment, partners will carry out site surveys in selected urban locations in coordination with public administration officers. These surveys will inform the design of the physical settings where hybrid events, referred to as P3 in the Grant Agreement, will take place, ensuring that both technical and experiential requirements are met.

All activities involving personal data will be governed by strict ethical and data protection standards. An impact assessment will be conducted prior to data collection, and protocols will be established in accordance with national, EU, and international guidelines. These processes will align with the project's Data Management and Ethics Management Plan.

The full implementation of the M⁴ System will most probably take place during a public cultural event in Torino, where the P3 event will occur. At this hybrid event, M⁴ will process and display cultural content developed earlier in the project, incorporating both curated material and user-generated content also gathered through the social media campaign and "attaCHbox" app. The system will detect and display emotional responses in real time, using colour-coded lighting and projections to reflect collective emotional states. M⁴ will also enhance cultural stimuli with multisensory elements, including sound, visuals, and scent, tailored to participant reactions. A central objective of the P3 event is to create a continuous two-way interaction between cultural stimuli and human responses. Emotional states triggered by the cultural experience will influence how the content is presented, and in turn, participants' interpretations and behaviours will shape the stimuli in real time. This dynamic feedback loop highlights the transformative nature of CH and explores how narrative, atmosphere, and multi-sensorial design, grounded in the TMT, can meaningfully engage and impact public audiences.

3.2.3 "attaCHbox" app

The attaCHbox application is designed as a concrete implementation of experimental results, to which it will contribute with simple tests carried out during the experiments: it is a customisable tool for museums to generate empathic participation and confidence based on cultural content. The creative user participation is required. So far, the focus has been on defining the conceptual framework of the application, analyzing similar digital platforms, and addressing key technical and privacy considerations. Research has explored different interaction models to assess users' emotional responses within a cultural setting. A significant part of this phase has been dedicated to ensuring GDPR compliance and privacy policies, particularly regarding the secure and ethical handling of user data. Aligning these aspects with WP4's participatory approach and co-creation principles has remained a key priority.

The next steps will involve refining the design specifications and collaborating with project partners to shape the app's functionalities. Future development will focus on creating a prototype that effectively captures and analyzes emotional responses while ensuring ease of use and meaningful engagement for both users and cultural institutions.

3.3 Stimuli and Prototypes

The stimuli of WP5 will consist of visual and audio cultural items developed in collaboration with WP4 and with standardized, validated emotional stimuli such as the Nencki Affective Picture System (NAPS) (Marchewka et al., 2014). These items will be pre-selected and scored to represent the extremes of the emotional spectrum.

3.3.1 Digital Prototypes and Experiences Framework

The prototypes are designed based on literature research on previous design initiatives and EU-funded projects, as well as theoretical, audience and stakeholder analysis from WP2, contextual investigations by WP6, and the scope definition of potential models through workshops (Table 2). Six digital experience prototypes will be developed in the T.4.2 according to guidelines identified in the T4.1 (derived from the integration of TMT, insights from prior EU projects, such as GIFT and EMOTIVE, and feedback from co-creation workshops) led by UNI JENA. Each experience prototype addresses **specific emotional and experiential objectives, including empathy, confidence, and cultural resilience.**

Building on EU-funded projects such as GIFT, EMOTIVE, eMotion, ViMM, and V-MUST, META-MUSEUM adopts and extends the following validated design principles:

- Personalization and emotional appropriation (GIFT)
- Emotion-driven storytelling and empathy (EMOTIVE)
- Physiological tracking for affective response (eMotion)
- Immersive VR/AR spaces (ViMM, V-MUST)
- Participatory design and community-driven interpretation (GIFT, eMotion)

The digital prototypes designed under T4.1, T4.2 are aligned with the following museum experience models: Sound/Audio Experience, VR/AR Visualization Experience, Physical & Digital Co-Creation Experience, Gamification Experience Personal Inventories, and Open Hybrid Experience.

3.3.1.1 *Sound/Audio Experience (environment/environmental storytelling) & Different types of Narration*

Prototypes will include atmospheric and narrative audio layers (e.g., ambient environments, object narration) embedded in digital interfaces to evoke empathy, imagination, and emotional resonance. This model will explore how visitors react to different audio conditions, multisensory stimuli and reconstruct inner narratives around exhibited artefacts, and how their confidence level will be affected by them.

- **Types of Audio Stimuli:** Sounds, music, voice, recording people's voices, individuation of archetypes or emotions/sentiments, sounds of different languages.
- **Experiential Focus:**
 - Soundscapes (e.g., historical environments)
 - Narrative object audio
 - Storytelling and oral memory recordings
- **Value:** Enhances emotional resonance, encourages reflective listening, creates an immersive effect and supports multisensory approach. It proposes an alternative experience to a pure visual one.

3.3.1.2 VR/AR Visualization Experience

This experience provides visual reconstructions that support historical contextualization and deeper cognitive processing through spatial interaction. Investigating how different ways VR/AR Visualization experience narration can impact visitor engagement and emotional response.

- **Types of Audio Stimuli:**
 - Immersive VR Experience
 - 2D Display VR Simulation
- **Experiential Focus:**
 - Enhance the user immersion experience
 - Investigating how different ways VR/AR Visualization experience narration impact visitor engagement and emotional response.
 - Interaction in the digital history space
 - Increase the user's sense of engagement to develop empathy
- **Value:** Strengthens memory encoding, promotes embodied cognition, and overcome time/place barriers for heritage access.

3.3.1.3 Physical & Digital Co-Creation Experience

Investigating how different ways Physical/Digital Co-Creation experience narration impacts visitor engagement and emotional response.

- **Types of Stimuli:** rankings, pinboards, shared experiences, physical/digital tools, replicas & physical interactions, need for dialogue & reflection spaces, bridging ancient & contemporary connections, perception of digital vs. physical experiences, tools for engagement
- **Experiential Focus:**
 - participatory tagging, physical replicas
 - visitor content submission and narrative layering
 - "Aura" of original objects
- **Value:** encourages agency, supports dialogic interpretation, and enables collective authorship of cultural narratives. It is possible to increase the user's engagement through shared participation and emotionally improve their empathy, resilience and self-confidence.

3.3.1.4 Gamification Experience

Narrative-driven tasks and role-playing mechanics will be integrated into mobile or browser-based systems. These games simulate historical decisions or ethical dilemmas, and will be used to **measure motivation, cognitive effort, and narrative immersion.**

- **Types of Gamification Stimuli:** questionnaires, roleplaying, scavenger hunt, Digital Gamification, Hybrid Gamification Models.
- **Experiential Focus:**
 - Investigating how different ways of Gamification experiences impact visitor engagement and emotional response.
 - Puzzle-solving, mission-based learning, RPG-style quests
 - Points and progression systems for feedback

- **Value:** promotes learning-by-doing, encourages narrative immersion, and sustains user motivation.

Table 2. T4.1& T4.2 Prototypes scope list

Examples of Stimuli & Prototypes	Potential Transformative Target	Core Interaction design Strategy	Reference Projects
Sound /Audio Based	Emotional resonance evokes memories and empathy—Empathy	Emotionally immersive soundscapes	EMOTIVE, GIFT
VR/AR Immersion	Promote cognitive processing and visual memory, Situation reconstruction—Confidence	Spatial simulation & virtual Immersion	ViMM, V-MUST
Co-Creation Platforms	Establish self-expression and cultural identity, Expression and collaboration—Social Bonding + Resilience	User-generated content & sharing	GIFT
Gamified	Enhance active exploration and sense of belonging, Task participation—Confidence + Motivation	Task-driven, goal-oriented play	GIFT, eMotion
Personal Inventories	Connecting personal memory with cultural identity, Belonging and identity—Inclusivity + Reflection	Personalized storytelling & feedback	GIFT

3.3.2 Physical Prototypes and Experiences Framework

The three museums, or rather, the three exhibitions where the experiments will be conducted, differ in theme, design, target audience, and narrative style. NCK, T4.3 leader, believes that **the physical prototypes should blend into the style of each respective museum, in order to create a seamless experience for the visitor.** Using the same prototype in all three museums could make it stand out and, in the worst-case scenario, appear less relevant to the people we aim to engage.

At **Museo Egizio**, the project partners have made a preliminary decision to focus the intervention on a food strike conducted by Egyptian workers around 1168 B.C. According to NCK, possible prototypes to engage the audience could include:

- A wooden board featuring life components such as work, food, love, housing, justice, and collaboration.
- Each visitor can re-rank the components and reflect on whether they would be willing to strike or fight for what they consider most important.
- Ideally, the board would have an Instagram-friendly design that encourages visitors to share photos of themselves and their life priorities.

At **MuséoParc Alésia**, the META-MUSEUM partners have not yet agreed on a specific theme for the experiments. One idea is to focus on what happened immediately after the great battle between the Romans and the Gauls in 52 B.C. The suggested theme would be resilience and re-orientation. How did the Gauls regroup, rebuild, and recover? Possible prototypes to engage the audience include:

- A set of glass cylinders accompanied by shiny glass marbles or replicas of Roman coins.
- Each cylinder represents a life strategy one might adopt after a disaster: providing for one's family, seeking revenge, helping to re-establish societal structures and functions, adapting to the conquerors' culture, learning new languages and skills, or fleeing to rebuild life elsewhere.

- Other options can also be included. Visitors cast their votes by placing marbles or coins in the corresponding cylinders, and the accumulated results will become visually evident over time.

Regarding **Museu d'Arqueologia de Catalunya**, the partners are still discussing the theme for the intervention. Suggested themes include colonisation/globalisation, courage, or empathy and personal identification with people living in Barcelona 2,000 years ago. Possible prototypes to engage the audience include:

- A magnetic board with pre-printed words and sentence fragments that can be assembled in multiple combinations.
- These could include words like Power, Rule, Exploit, Slave, Foreigners, Wealth, “is important to,” “makes the world go round,” “must come to an end,” and so on.
- The visitor spins a wheel of fortune, which lands on a character from Roman times, a slave, a gladiator, a senator, etc.
- Based on the assigned role, the visitor constructs a sentence that reflects that character’s point of view. For example, if you are a gladiator, you might create a sentence like “I want + Freedom” or “Entertainment + makes the world go round.” The aim is to show that history is always told from a certain perspective — and that the visitor has the power to shift that perspective.

The physical prototypes are intended as:

- Tools to build one's hierarchy of values/opinions/reflections, making it visible to others, who in turn can do the same (tendencies and exceptions emerge);
- Voting systems where the individual choice stands testified, nurturing a sense of self-confidence;
- Tools to create content relationships between objects, showing the richness of possible interpretations;
- Tools to co-create alternative captions, that remain physically on display;
- Changes in colour/shape of the background, or of the information apparatus (even by processing images), to change the physical scenario in which the same object/content is presented

These systems always involve the combination of questionnaires, in which **a self-assessment of confidence and a range of emotional states is also requested.**

3.4 Identification and Recruitment of Participants

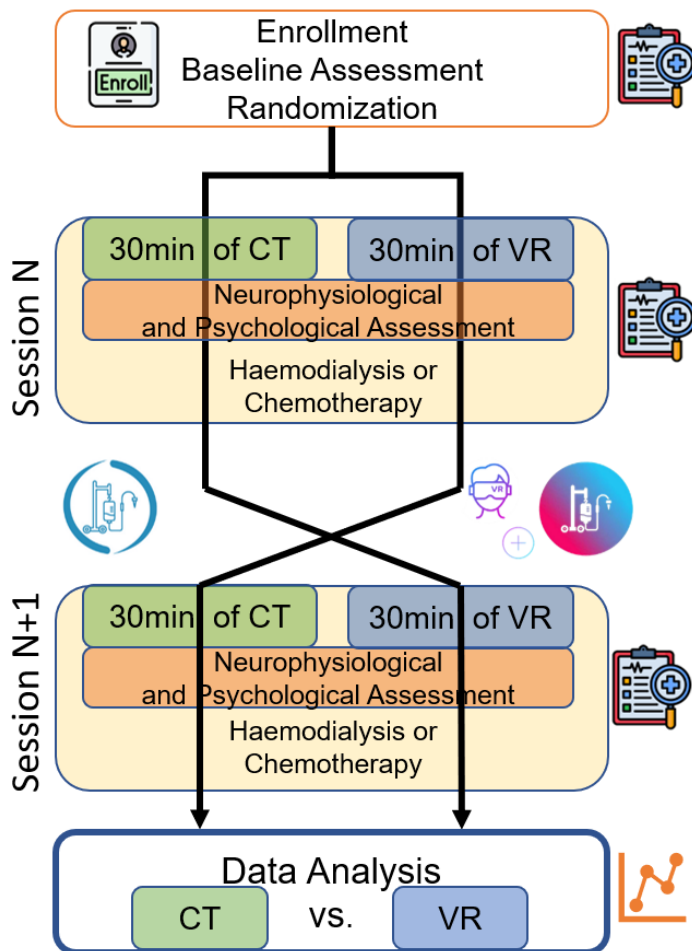
Since the META-MUSEUM project involves a multi-center approach and various types of experimental pilots, different sampling procedures will be employed accordingly.

For WP5 (laboratory-based investigations) a sample of 30-40 healthy English-speaking adults [see power analysis (i) below] with no history of disorder that prevents them from standing / walking or history of epileptic conditions will take part. Participating in this study will be on a voluntary basis and participants will be recruited at the VU. The local ethics committee of the Faculty of Behavioural and Movement Sciences in Amsterdam approved the experimental procedure prior to the start of data collection. Once somebody expresses interest in participating in the study, they will receive the information letter with all the information about the study and the specific experimental procedures. Before the recording session, the experimenter will explain the study and procedures again and clarify that they will be free to withdraw from the study at any time, without stating a reason. Afterwards, the subjects will sign the informed consent. In case specific data (e.g. audiovisual material) is being used for teaching or presentation, then separate explicit consent for this is asked.

For WP6 (measurements in museums), the target demographic for this WP includes a minimum of 70 participants per museum for each measurement [baseline and after the intervention, see power analysis (ii) below], aged between 18 and 65 years, with a balanced representation of male and female participants. Participation will be voluntary, both through social media calls and personal contacts, and involving local associations and civic centers. Recruitment will be carried out by the museums, following ethical approval and after obtaining informed consent from all participants.

For WP7 (experiments in hospitals), this WP will involve 14 patients undergoing dialysis and 14 patients undergoing chemotherapy, as specified in the Grant Agreement and illustrated in Figure 5. Participation will also be voluntary, and participants will be recruited by UNIROMA1 after obtaining ethical approval and informed consent.

Figure 5. WP7 -experiments in hospitals protocol



For WP8 (hybrid event), there will be two activities: the first will involve neurophysiological measurements conducted within a designated area, involving at least 30 participants [see power analysis (i) below]. The second will be a form of 'emotional self-evaluation' carried out in a public space, with a minimum of 70 participants, both on site and off site [see power analysis (ii) below]. Participation will be voluntary, following ethical approval and after obtaining informed consent from all participants.

To engage audiences and promote the upcoming events, a coordinated social media campaign will be launched two weeks prior to each hybrid event. This campaign, known as the M⁴ Social Media

Call, will include teaser content developed in earlier project phases, encouraging participation both in person and remotely. Through the integration of the “**attaCHbox**” app, users will be able to interact with preview content and contribute their own material, which will later be featured during the events.

A priori power analysis

(i) Laboratory and clinical setting measurements: a sample size calculation was performed using G-Power 3.1 software based on the data reported in the study by Giorgi et al., (2023), which used the same type of devices and similar neurometrics. Considering the Emotional Index from their work, which will also be used as the primary outcome in this project, and assuming a similar effect size (i.e., 0.8), for a two-tailed paired-sample test with a significance level (alpha) set at 5% and a test power (1-beta) of 95%, a minimum of 23 subjects per test is required. Taking into account a 30% rate for drop-outs and data potentially affected by movement artefacts that cannot be corrected in post-processing, the sample size is adjusted to about 30 subjects per experiment.

(ii) Museums measurements and hybrid public event: using G-Power 3.1 software, an a priori power analysis was conducted which revealed that a total of 54 participants per site is needed to achieve a statistical power of 0.95, assuming a small to medium effect size of $f = 0.15$ in a repeated-measures design within-subject interactions, with an alpha level of 0.05 and psychometric measurements taken at baseline and follow-up. To account for an anticipated dropout rate of around 30%, it is suggested to recruit at least a total of 70 participants per site.

3.5 Data Analysis Plan

Descriptive Statistics: Mean, mode, median, standard deviation, and range for numerical quantitative data; percentage frequencies for categorical quantitative data.

Inferential Statistics: After conducting statistical assumption diagnostics and determining the level of measurement (continuous, discrete, nominal, or ordinal) for the assessed variables, the appropriate parametric or non-parametric bivariate tests will be applied. More specifically, for the **laboratory-based measurements**, statistical analyses from the VU partner will be performed using in-house Matlab (<https://www.mathworks.com>) scripts and JASP (<https://jasp-stats.org>), to provide both Bayes factors and p values. Bayes factors will allow us to differentiate between evidence of absence and evidence of the presence of an effect and complement traditional frequentist statistics as p-values cannot quantify evidence for the absence of an effect. Traditional bounds of $BF_{10} > 3$ will be used to infer the presence of an effect and $BF_{10} < 1/3$ to infer the absence of an effect (Keyes et al., 2020). Pearson Correlation Coefficients (r), Bayes factors and p values will be reported. Two-tailed tests will be indicated by BF_{10} , i.e. $p(\text{Data}|H_1)/p(\text{Data}|H_0)$ while one-tailed tests will be indicated by BF_{+0} . Where ANOVA will be used, BF_{incl} will be used which reports the probability of the data given a model including the factor divided by the average probability of the data given the models not including that factor. When using t-tests, normality of data will be examined using the Shapiro-Wilk's test. If normality will be preserved, t tests and t-values will be applied and if not, Wilcoxon signed rank tests will be used, as indicated by W values. Default priors for Bayesian statistics will be applied. In addition, for the **experiments in hospitals** measurements, it is expected a continuous pattern in the collected data. Accordingly, a repeated-measures ANOVA will be used for data analyses. Post-hoc analyses will be performed with Tukey correction. If distributions will not be normal (tested with the Shapiro-Wilk test), non-parametric analysis will be used (Friedman analysis for repeated measures). Further, for the **project-specific questionnaire data collected in museums and the data collected during the hybrid event**, all survey predictors will be tested in various combinations across multiple regression models. The models with the best fit will be selected to report the significant estimate(s).

Qualitative Data: Descriptive content analysis using a hybrid coding technique (combining deductive and inductive coding) to explain variability in outcome measures pre- and post-interventions.

3.6 Quality Assurance, Assessment Risks and Mitigation Strategies

Ensuring data quality across diverse experimental contexts in the META-MUSEUM project requires tailored approaches for each experiment and data type (Table 3). In general, **for all quantitative data**, the focus will be on identifying and correcting anomalies such as missing values or outliers through statistical and cleaning techniques. To maintain long-term data integrity, periodic audits, regular and scheduled reviews of the data will be conducted to detect inconsistencies, validate data accuracy, and ensure compliance with data quality standards. For example, audits of measurements for specific participants may involve checking for unexpected increases or decreases in values compared to their previous measurements.

For the project-specific questionnaires conducted in museums, a lower-than-expected participation rate will be addressed by recruiting 30% more participants than originally planned. To mitigate potential translation inconsistencies in multilingual versions of the survey, all translations will be verified by both native speakers and experts in the subject matter. Furthermore, methodological discrepancies will be minimized through active supervision by representatives of the META-MUSEUM project.

In the context of **hospital-based experiments (WP7)**, challenges include the complexity of recruiting patient participants and obtaining necessary clinical ethical approvals. To minimize delays, the ethical approval process will be initiated as early as possible.

For **laboratory investigations**, two primary challenges are anticipated. First, the technical synchronization of the Mindtooth system with VU's setup will be handled by leveraging the extensive experience of both the UNIROMA1 and VU teams. A UNIROMA1 researcher will personally deliver and set up the equipment to ensure seamless operation. Second, if difficulties arise in recruiting participants within the two-month timeframe, an amendment to the ethical protocol will be requested to allow paid participation, using the allocated budget for this purpose.

Regarding **qualitative data**, the risk of subjective bias will be addressed by applying structured data collection methods, predefined coding schemes, and rigorous training for data collectors. Triangulation, member checking, and peer reviews will further enhance data credibility, and all sources and interpretations will be thoroughly documented.

Table 3. Data Quality Assurance, Assessment Risks, and Mitigation Strategies

Context	Risk	Mitigation Strategy
Quantitative Data Collection	Data quality issues (e.g., outliers, missing values)	Apply statistical methods for detection; implement data cleaning procedures.
	Long-term data integrity	Conduct periodic audits and maintain version-controlled data management.
Project-Tailored Questionnaire	Lower than planned participation rate	Recruit 30% more participants to ensure sufficient sample size.
	Differences in meaning across language versions	Verify translations with native speakers and subject-matter experts.

	Methodological discrepancies vs. planned procedure	Ensure supervision by META-MUSEUM project representatives.
Experiments in Hospitals	Difficulty recruiting patient participants	Begin ethical approval process early to enable timely recruitment.
	Requirement for Clinical Ethical Approval	Submit ethical approval request as early as possible to avoid delays in data collection.
Laboratory Investigations	Synchronization of Mindtooth software with VU setup	Leverage partner expertise; UNIROMA1 researcher to deliver and verify equipment setup on-site.
	Difficulty finding participants during testing period	Amend ethics to allow paid participation if needed; budget available for this contingency.
Qualitative Data Collection	Subjectivity and potential bias in interpretation	Establish clear guidelines; use structured methods and predefined coding frameworks.
	Inconsistent data collection	Train data collectors; apply triangulation and member checking for validation.
	Accuracy and traceability	Maintain detailed documentation and conduct peer reviews.

4 META-MUSEUM Interpretation Model

4.1 General Structure of the Interpretation Model

Creating an interpretation model for project measurements can be a complex task, particularly in the context of an innovative initiative like the META-MUSEUM. This complexity increases when measurements are collected from diverse population groups and interventions. Although all measurements aim to address the same overarching research questions, it becomes intuitively clear that their reliability must be high, especially when they are not merely used for broad statistical summaries (e.g., calculating group means with relatively low standard error), but for drawing meaningful, case-specific interpretations (Bergman, 2017). This is precisely the case with the META-MUSEUM.

To ensure that project results are interpreted as accurately and meaningfully as possible, a robust Interpretation Model must be established. This model should be built on four key components:

The TMT: The theoretical framework that underpins the project's objectives and activities (there is an overview of this theory in Section 2).

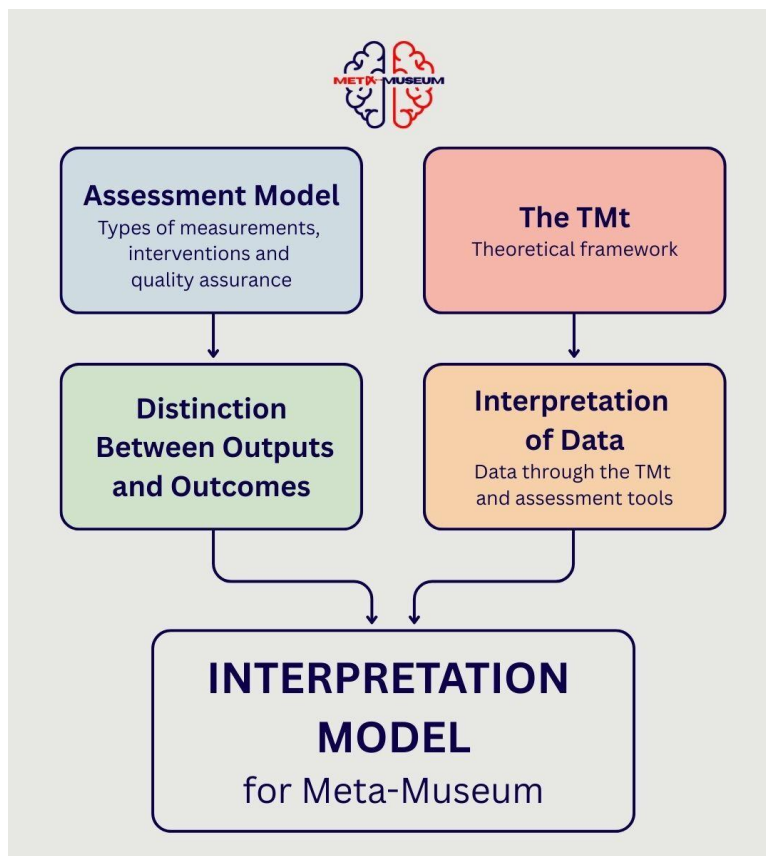
The Assessment Model: This includes the types of measurements used, the nature of the interventions, and the quality assurance mechanisms in place (described in detail in Section 3).

Distinction Between Outputs and Outcomes: A clear distinction between the activities carried out or completed in a project (outputs), which contribute to achieving specific results (outcomes), emphasizing that outcomes are the direct results of those activities.

Interpretation of Data: The analytical process of interpreting data through the lens of the TMT and the assessment tools, specifically to address the project's research hypotheses.

Together, these four components form the Interpretation Model of the META-MUSEUM, which is represented in an integrated Interpretation Model, as depicted in Figure 6 below.

Figure 6. META-MUSEUM Interpretation Model Summary



4.2 Online Workshops as Interpretative Examples under the TMT Framework

OPI-PIB designed and coordinated internal **online workshops** in April 2025, with the participation of all consortium members, as interpretative examples under the TMT framework. These workshops can serve as practical examples of how interpretation methods apply to cultural artefacts, reinforcing psychosocial transformation through historical narratives and interactive engagement. More specifically,

Museo Egizio: During this workshop, participants were divided into two independent groups. Despite working separately, both groups arrived at remarkably similar conclusions regarding the historical strike described in the ancient papyrus. Key elements identified in the story include:

- ✓ **Unity and Organization:** The papyrus tells a story of a community bound together by shared purpose. It speaks to the power of collective action, even in a rigidly hierarchical society like ancient Egypt. The strike reflects not only solidarity but possibly the influence of a heroic

leader who guided the protest. This resonates with themes of resilience, belonging, and the potential of organized individuals to effect change.

- ✓ Desperation and Rebellion: The strikers appeared to have no alternative but to take action. Their uprising was driven by abuse, hunger, and deplorable working conditions, a fight born from a place of having nothing left to lose.
- ✓ Courage and Collective Voice: The act of striking against powerful authorities took immense bravery. It was not only about demanding justice for oneself but also about standing up for others and making their voices heard, even under threat of punishment.

Drawing from these elements, it is suggested an intervention centered around the theme of unity and collective empowerment, with the following objectives:

- ✓ **To inspire a sense of empowerment** by showing that individuals, when united, have the power to shape their reality.
- ✓ **To encourage reflection** on the type of society we aspire to live in, a society where solidarity matters and individuals feel their actions can make a difference.

The story presented to visitors would highlight:

- ✓ **The transformative power of unity**, how individual efforts, when organized, can bring about real change.
- ✓ **The dignity of the marginalized**, asserting their right to resist unjust treatment.
- ✓ **The heroic leader figure**, aligning with the universal archetype of the Hero who inspires and leads collective action.

Proposed methods:

- ✓ **Interactive engagement**: Visitors will be invited to reflect on thought-provoking questions. Their responses could be visualized through live data (e.g., charts of responses, keyword analysis).
- ✓ **Immersive soundscapes**: Recreate the atmosphere of the strike through layered sound design, using ambient noises, chants, and voices from the period.
- ✓ **Modern parallels**: Introduce examples of contemporary protests to bridge ancient and modern struggles for justice.

The evaluation criteria of the intervention can be:

- ✓ Shifts in visitor attitudes toward individualism vs collectivism.
- ✓ Increase in self-confidence and perceived ability to effect change.

MAC Barcelona: Key themes that emerged during the workshop include:

- ✓ Parallels between Ancient and Modern Life: The exhibition draws implicit comparisons between Roman society and today's world, highlighting familiar values, institutions, and challenges.
- ✓ Colonialism and Globalism: Rome is portrayed as an early example of an imperial power, raising complex questions about expansion, domination, and cultural exchange.
- ✓ Empathy and Human Emotion: This theme is especially vivid in the exhibition's video content, which emphasizes personal experiences, emotions, and human values.
- ✓ Courage and Risk: Particularly reflected in the mosaic depicting the circus, themes of bravery, performance, and confrontation are prominent.
- ✓ Structural Ambiguity: The exhibition lacks clarity in its dual-layer structure. Videos and artefacts are presented in parallel but not clearly connected. This disconnect should be addressed early in the visitor experience.
- ✓ Accessibility Issues: Video durations are long due to multiple language versions, which may discourage full viewing. Skipping the opening video results in missing the conceptual framework of the exhibition.

Based on these observations, proposed intervention themes include:

- ✓ **Empathy:** Encourage visitors to emotionally connect with individuals from the past.
- ✓ **Freedom:** Explore differing definitions and values of freedom in Roman and contemporary contexts.
- ✓ **Courage and Identity:** Use the figures of gladiators and charioteers (Auriga) to explore personal strength, agency, and resilience.
- ✓ **Interpretation and Reflection:** Empower visitors to formulate their own interpretations of historical narratives.

Proposed Methods:

- ✓ Visitor Engagement: Include prompts and interactive stations to gather visitor reactions and thoughts.
- ✓ Story-Driven Objects: Present artefacts tied to personal stories from Roman times, enhancing emotional engagement.
- ✓ Co-Creation Experience: Begin by connecting to modern-day challenges (e.g. prejudice, migration, personal crises); encourage visitors to discover how these issues were experienced in Roman society.
- ✓ 'Character Cards': Provide visitors with fictional Roman personas, prompting them to answer questions and explore the exhibition from that perspective.
- ✓ Comparative Reflections: Highlight similarities and differences in values, emotions, and daily life between then and now.
- ✓ Freedom and Values: Prompt visitors to reflect on the meaning of freedom and how values evolve over time.

Muséoparc Alésia: The focus was on telling the story of the Battle of Alesia from the Gallic perspective, rather than glorifying Roman victory. Key themes include:

- ✓ **Consequences of Defeat:** The aftermath of the lost battle is a powerful story of resilience, learning through failure, and maintaining dignity despite loss.
- ✓ **Uncertainty and Imperfection:** The battle was hard-fought on both sides, with the outcome uncertain until the end. It emphasizes that even great efforts can end in defeat, and that's part of life.
- ✓ **Sacrifice and Cultural Identity:** How far are we willing to go to defend what we value? The story is about self-sacrifice and the enduring importance of identity and heritage.
- ✓ **Victory's Ambiguity:** Roman triumph came at a cost. Post-battle narratives reveal how the blending of cultures influenced both sides, questioning whether victory achieved through violence can ever be truly satisfying.
- ✓ **Multicultural Legacy:** Roman and Gallic cultures merged, leaving a complex heritage. This interaction forms the roots of modern multicultural European identity.
- ✓ **Epic Storytelling:** The Battle of Alesia is compelling because it is rich with drama—strong leaders, vast armies, innovative engineering, and the emotional weight of irreversible choices.

Based on the above elements, the intervention aims to deepen visitor engagement through active reflection and emotional connection to the story using the following methods

- ✓ Reflective Questions: Pose open-ended questions that encourage visitors to think deeply about the events and characters.
- ✓ Personal Interpretation: Allow space for visitors to re-tell or interpret the story in their own words, focusing on the moments that resonated most.
- ✓ Narrative Reconstruction: Visitors could select scenes or characters to reconstruct the story from a new angle, imagining alternative outcomes or untold perspectives.

In conclusion, these are the main takeaways from these workshops:

- Empowering Unity & Resilience (Museo Egizio Workshop):
 - ✓ Aligned with standardized measurement of confidence and well-being;
 - ✓ Cultural storytelling about protest and collective action reinforced unity and resilience, demonstrating that individuals can shape their circumstances through organized social efforts.
- Empathy & Comparative Perspectives (MAC Barcelona Workshop):
 - ✓ Aligned with systematic evaluation of emotional states and belief transformation;
 - ✓ Participants explored ancient Roman social challenges alongside modern dilemmas, fostering self-awareness and resilience by recognizing continuity in human experiences across time.
- Personal Interpretation & Transformation (Museoparc Alesia Workshop):
 - ✓ Aligned with encouraging active participation, perspective-shifting, and cultural reflection.
 - ✓ The narrative of battle outcomes and cultural blending framed failure as transformation, helping visitors reframe adversity as an opportunity for growth.

4.3 Insight Integration and Interpretation Matrix (Why and How Results are Used)

Assessment findings are both evaluative and formative, feeding directly into the development of project outputs and refining the TMt theory itself. Assessment insights will:

- Compare the first phase (status quo measurements) with the second phase, which corresponds to the actual pilot implementations within WP6. The first phase, in which no changes will be introduced, will serve as a control baseline against which the outcomes of the second phase will be evaluated.
- Inform WP4, which develops narrative components and best practices for designing CH content that elicits emotional and cognitive transformation.
- Support the iterative refinement of TMt within WP2, enabling theory to evolve in response to empirical findings.
- Help tailor engagement strategies to different audience typologies identified during WP2 activities, such as the Stakeholder and Audience Analysis (Margaritis, et al., 2025), ensuring relevance across demographic and cultural contexts.
- Provide evidence-based validation for technological tools (e.g., the M⁴ adaptive system in WP8) that aim to personalize CH experiences in real time, optimizing for emotional resonance and increased confidence.

In this way, **the project's assessments function both as measurement tools and as drivers of transformation**, contributing to theoretical development, practical application, and societal impact. To this end, it is essential to clearly distinguish outputs, outcomes, and measurement methods across the project's tasks, to develop **an interpretation matrix, always viewed through the lens of TMt**, as summarized in Table 4.

More specifically, **the integrated use of neurophysiological, affective, and experiential metrics enables a deep understanding of how individuals emotionally and cognitively engage with CH**. This multifaceted approach reveals that heritage is not merely about preservation, but an active medium for personal and societal transformation.

Neurophysiological Insights: Through technologies such as EEG, GSR, and postural analysis, the project uncovers **subconscious emotional and attentional responses to cultural stimuli**. EEG readings, for example, reveal that increased alpha symmetry correlates with greater approach motivation, while heightened theta activity signifies elevated cognitive effort. These markers provide evidence that storytelling in heritage contexts, particularly narratives of resilience and transformation, engages the brain on both emotional and intellectual levels.

Similarly, GSR data reflects autonomic nervous system activity, **linking skin conductance levels to arousal and stress**. When participants engage with emotionally rich cultural content, their **physiological responses provide insights into the potential role of CH in influencing emotional resilience and cognitive flexibility**. Postural indices further contribute to understanding these effects: reduced sway and unconscious backward lean may indicate attentional captivation and aversion, respectively, **offering opportunities for curators to refine content for emotional resonance**.

Psychometric Measures: Complementing the physiological data, affective and well-being assessments, such as the PANAS scale, general confidence scale, and beauty assessment tool, highlight **changes in self-perception, mood, and aesthetic appreciation**. Cultural engagement, particularly when rooted in emotionally charged narratives (e.g., failure and resilience discussed during the Museoparc Alesia workshop), fosters an adaptive mindset. Participants often **report increased confidence, viewing challenges as opportunities for personal growth**.

The aesthetic dimension also could play a role, to a certain extent, although not particularly related with the META-MUSEUM core. Heritage is experienced not only visually but as an emotionally resonant encounter, where beauty becomes linked to deeper psychological significance. This connection could strengthen both self-esteem and engagement, showing that **cultural beauty extends beyond aesthetics into meaningful personal reflection**.

Experiential Feedback: On-site surveys and personalized questionnaires reveal visitor experiences across diverse cultural settings. These tools **connect individual expectations and post-visit reflections to broader themes such as identity, empathy, and resilience**. For example, co-creation workshops at MAC Barcelona prompt self-awareness by encouraging visitors to draw parallels between historical and modern life, deepening the sense of cultural continuity and collective memory.

Technological Integration for Real-Time Engagement: The development of the M⁴ system introduces real-time monitoring² of emotional and physiological states, offering insights into the effects that narratives/objects/cultural contents have on the audience intended as a group providing feedback. By detecting and processing several emotional and affective metrics, the system makes **heritage sites “responsive subjects” able to “dialogue” with users' interpretation and reaction**. **Prototyping and Immersive Storytelling:** Digital (VR/AR, gamification) and physical (tactile objects) prototypes further enrich engagement by empowering visitors to co-create narratives. **These experiences reinforce agency, encourage empathy, and facilitate cultural reflection**. Workshops utilizing character cards or battlefield simulations help visitors reinterpret history through their own lens, transforming heritage into a living dialogue rather than a static exhibit.

² Examples of parameters monitored with HealthyPi Move which is an open-source biometric monitor in a watch form factor): ECG, Heart-rate (from ECG or PPG Wrist or Finger sensor), Heart-rate variability (HRV) (from ECG or PPG Wrist or Finger sensor), PPG (from wrist or/and finger PPG sensor), SpO₂ (from wrist or finger PPG sensor), EDA/GSR, Respiration Rate (ECG derived), Temperature, Activity levels and step count, Energy expenditure (calories burned). <https://www.crowdsupply.com/protocentral/healthy-pi-move>

Table 4. META-MUSEUM Interpretation Matrix

Output Category	Outcome	Measurement Method	Interpretation Approach (Using TMT)
Neurophysiological: <i>Electroencephalography (EEG)</i>	Assessment of cognitive workload, attention, and emotional engagement	EEG engagement; Brain wave analysis (theta, alpha bands); Approach-Withdrawal index; Cognitive Effort Index; <i>Higher symmetry in alpha band ► higher Approach to the stimulus</i> <i>Higher frontal activation in theta band ► higher Cognitive workload</i>	Emotional responses and cognitive engagement are tracked, offering insights into subconscious interactions with CH . These observations suggest that cultural storytelling may play a role in supporting resilience and attentional processes .
Neurophysiological: <i>Galvanic Skin Response (GSR)</i>	Assessment of Autonomic nervous system engagement	Skin Conductance Level (SCL) Estimation; <i>Related to arousal and stress levels</i>	Capturing physical reactions to cultural narratives provides evidence of the transformative potential of CH , offering insights into how cultural engagement might support emotional resilience and cognitive flexibility .
Neurophysiological: <i>Postural indices</i>	Assessment of Postural activity related to attentional and / or emotional state.	Emotional Estimation Variable: sway variability & mean position of the COP in the anterior-posterior direction; <i>Situations that are highly attentional captivating ► a (temporary) reduction in sway variability.</i> <i>Unpleasant items ► small spontaneous (unconscious) backward lean</i>	
Adaptation of psychometric measures across tasks of WP5, WP6 and WP7	Integration of psychometric measures with participants' characteristics, taking into consideration the clinical setting	Affective State: Positive Affect and Negative Affect Scale (PANAS) Well-Being: General Wellbeing Questionnaire Confidence: General Confidence Scale Aesthetic Experience: Beauty Assessment Scale	

			significance that enhances self-confidence and engagement .
Positioning	Localization of users in terms of positioning and time	Determination of indoor positioning solutions through ultra-wideband sensors in order to synchronize the localization of users with the neuro-physiological measurements	Indoor localization will be used to create heatmaps to estimate the areas where users linger the most . It will also be used to verify whether there is a correlation between emotional peaks and the location of CH .
Data collection via site surveys across cultural settings (demographic, expectations, post-visit evaluations, etc.)	Insights into visitors' museum experiences, personality traits, and perceived cultural engagement	Customized Questionnaire (see section 3.1.2.4)	Visitors reflect on their emotional states before and after engagement , linking cultural narratives to personal growth and reinforcing resilience through historical storytelling . <i>*Example workshop: MAC Barcelona: Visitor-driven co-creation encourages self-awareness and emotional reflection.</i> Analyzing visitor interpretations of cultural narratives enables tailored interventions that highlight themes of identity, empathy, and resilience , reinforcing how heritage strengthens social cohesion . <i>*Example workshop: MAC Barcelona: Comparisons of Roman and modern life reinforce cultural continuity.</i>
Development and Implementation of the M⁴ System for real-time emotional monitoring	Enhanced interactive cultural experiences based on emotional and physiological responses	58 distinct human emotional, affective, physiological, and urban space metrics, using emotional, affective, and physiological sensors; recognition software; environmental equipment (such as HVAC systems); wireless sensor networks	Adaptive heritage experiences respond to visitor emotions in real time , making engagement personalized and transformative , strengthening confidence and emotional immersion . During the hybrid event, visitor-led heritage discussions stimulate engagement in contemporary issues through historical parallels , fostering resilience, self-confidence, and identity formation as part of an ongoing cultural dialogue .
Implementation of digital prototypes (VR/AR, gamification, co-creation experiences)	Increased visitor engagement, confidence, empathy, and resilience	Selection of the measurements described above.	Immersive storytelling actively involves visitors in shaping narratives , reinforcing personal agency in cultural interpretation and encouraging visitors to experience heritage as an evolving dialogue .

			<i>*Example workshop: MAC Barcelona: Character cards foster interactive and immersive interpretation.</i>
Physical prototypes tailored to interpretation themes	Encouraging active participation, perspective-shifting, and cultural reflection	Selection of the measurements described above.	Cultural objects become touchpoints for emotional reflection , helping individuals reinterpret historical themes through their own lived experiences , reinforcing self-awareness and resilience . <i>*Example workshop: Museoparc Alesia: Historical battle reflection encourages personal storytelling.</i>

In conclusion, the META-MUSEUM project illustrates how CH can actively foster **confidence**, resilience, empathy, and identity formation through well-structured interpretation methodologies. **By connecting emotional engagement with cognitive activity, fostering reflection and personal processing, visitors are empowered to see change as natural, resilience as adaptability, and obstacles as opportunities.**

The transformative nature of cultural heritage (CH) stems precisely from its ongoing and evolving dialogue with users, shaped by their continually renewed interpretations in response to contemporary contexts. Neuroscience, by exploring the body's unconscious responses, combined with psychological and social sciences, which examine conscious reactions to stimuli, can together offer a deeper understanding of our relationship with CH.

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Annex : Scales

GENERAL CONFIDENCE SCALE

(extracted by the original paper of Keller et al., 2011)

Assess the agreement with the following sentences from 1 (no agreement at all) to 6 (absolute agreement). The scale is based on a 6-point Likert-type scale.

Item	S
1. In the future, society will be functioning as well as today.	
2. Our society is well equipped to solve future problems.	
3. The future safety and security of our population is assured.	
4. Our society has a bright future.	
5. Nowadays, things seem to be getting more and more out of control. (R)	
6. Altogether, we live in a safe and secure time.	

Generic Wellbeing Questionnaire (Thomson & Chatterjee, 2014)

Generic Wellbeing Questionnaire Full 12-item version

Please circle a number for each statement to indicate how much you agree with it.

1) I felt happy

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
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2) I felt engaged

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

3) I felt comfortable

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

4) I felt safe and secure

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

5) I enjoyed the company of other people

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

6) I talked to other people

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

Generic Wellbeing Questionnaire Full 12-item version (continued)

Please continue to circle a number for each statement to indicate how much you agree with it.

7) I was interested

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

8) I enjoyed it

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

9) I was amazed

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

10) I was entertained

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
-----------------------	---------------------	-----------------------	-----------------	----------------------

11) I felt confident

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
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12) I felt healthy

None of the time 1	Not very often 2	Some of the time 3	Very often 4	All of the time 5
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PANAS (extracted from the page of The Ohio State University)

Positive and Negative Affect Schedule (PANAS-SF)

Indicate the extent you have felt this way over the past week.		Very slightly or not at all	A little	Moderately	Quite a bit	Extremely
PANAS 1	Interested	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 2	Distressed	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 3	Excited	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 4	Upset	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 5	Strong	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 6	Guilty	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 7	Scared	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 8	Hostile	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 9	Enthusiastic	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 10	Proud	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 11	Irritable	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 12	Alert	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 13	Ashamed	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 14	Inspired	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 15	Nervous	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 16	Determined	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 17	Attentive	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 18	Jittery	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 19	Active	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PANAS 20	Afraid	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

The Beauty Assessment Scale (BAS; Iosa et al., under review).

BAS English Version	0-10	BAS Italian Version	0-10
How beautiful is it?		Quanto è bella/o?	
How much could others like it?		Quanto potrebbe piacere agli altri?	
How much do you like it?		Quanto ti piace?	
How much contentment does it raise?		Quanto suscita appagamento?	
How much does it raise positive sensations?		Quanto suscita sensazioni positive?	
How much does it raise positive emotions in you?		Quanto ti suscita emozioni positive?)	
How much does it make you think or reflect?		Quanto ti fa pensare, riflettere?	
How surprising is it for you?		Quanto ti sorprende?	
BAS Average Score =		BAS Punteggio Medio =	