MindSpaces

Art-driven adaptive outdoors and

indoors design

H2020-825079

D6.1

Roadmap towards the implementation of the MindSpaces platform

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Abstract

D6.1 provides the time-plan for the development of the MindSpaces platform. It will present the functionality of the modules that will be developed within MindSpaces and of the platform as a whole. Specifications for the technical infrastructure will be provided. In addition, a detailed description of the resources needed to achieve the aforementioned functionality are also included.

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History

Version	Date	Reason	Revised by
V0.2	30/04/2019	Creation of ToC and initial content -Distribution to MindSpaces consortium	
V1.0	27/5/2019	Submitted for internal review	Petros Alvanitopoulos
V2.0	29/5/2019	Revised after internal review by NURO	Petros Alvanitopoulos
V3.0	30/5/2019	Minor changes, formatting figures, tables and adding footnotes,	Petros Alvanitopoulos

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Abbreviations and Acronyms

API(s)	Application Programming Interface(s)
3D2PG	3D To Parametric Geometries
BSDCS	BIO-Signal Data Collection Service
BSPM	BIO-Signal Processing Module
BV	Basic Version
CAD/CAM	Computer-Aided Design And Manufacturing
CNN(s)	Convolutional Neural Networks
CPU	Central Processing Unit
CS	Classification of Services
CSV	Comma Separated Values
DB	Database
DC	Data Collection
DM	Definition of Machines
DoA	Description of Actions
DS	Dummy Service
EEG	electroencephalogram
FAD	Final Architecture Design
FMF	Fundamental mapping functionality
fps	Frames per Second
FTP	File Transfer Protocol
GM	Geometry Mapping
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSP	Graph Signal Processing
GSR	Galvanic Skin Response
H.264	Video compression format
HBA	Human Behavior Analysis
HR	heart rate
IAM	Advanced Methods for Indoor
IBM	Basic Methods for Indoor
IMU	Inertial Measurement Unit
ISS	Indoor scanning system
JSON	JavaScript Object Notation
KB	Knowledge Base
KBP	Knowledge Base Population
k-NN	k-nearest neighbours
KR	Key Results
MJPEG	Motion JPEG (video compression format)
MMPA	Mobile Mapping Platform Adjustments
MMPD	Mobile Mapping Platform Development
MP4	digital multimedia container format
MS	Milestone
OP	Operational Prototype
P	Prototype
RA	Research Activity

RAM	Random-Access Memory
RDF	Resource Description Framework data model
RO	Research Objective
RV	Refined Version
SD	Service Definition
SFM	Structure-From-Motion
SIR	Semantic Integration and Reasoning
SLAM	Simultaneous Localization and Mapping
SLS	Structured light system
SoA-R	State-of-the-art Review
SR	System Refinement
SVM	Support Vector Machines
TA	Technical Activities
TA	Textual Analysis
TGS	Text Generation Service
TM	Texture Mapping
TO	Technical Objectives
TP	Texture Proposal
TRL	Technology Readiness Levels
UAM	Advanced Methods for Urban
UAV	Unmanned Aerial vehicle
UBM	Basic Methods for Urban
UC(S)	Use Cases
UTF-8	8-bit Unicode Transformation Format
V1	Version 1
VDCSBA	Visual Data Collection Service for Behavioural Analysis
WP(s)	Workpackage(s)
XML	eXtensible Markup Language

Executive Summary

This deliverable is connected to the project milestone MS1 “Project setup and platform development roadmap”, which involves the accomplishment of the MindSpaces’s architecture roadmap.

First an overview of the MindSpaces is provided. Then a high-level view of the envisioned architecture for the MindSpaces platform is presented, illustrating the conceptual architecture foreseen in the DoA document. A description of the modules that will be developed within MindSpaces follows. The functionality and specifications, per system component are described. In addition, for each module of the system, to support the aforementioned functionalities the required resources and the development milestones, are provided.

To enable the integration of MindSpaces’ services, the available tools, practices and integration patterns are described and the contextualization of MindSpaces system is depicted. The MindSpaces platform concept is introduced in a manner that facilitates an early abstraction and classification of MindSpaces’ components. A development plan and integration model are included.

In addition, a vision of the proposed pilot use cases is included. The motivation per pilot use case and the related scenario are described.

Finally, a global project timeline, describing the platform’s scheduled iterations and the levels of functionality at the project milestones is presented.

This roadmap represents a common accord and a technical agreement between the partners responsible for developing and deploying services and components in the MindSpaces platform. It defines the context for the implementation of the platform. Addresses all the main concerns related to this type of development and should serve as a guide for developing and integrating any component.

Table of Contents

1 INTRODUCTION

This document presents a roadmap and describes the plan to develop the MindSpaces platform. The objective of the deliverable is to specify in detail: (i) the progressively increasing functionality (in particular at the time points of the milestones) of the MindSpaces modules/activities as well as of the platform as a whole, (ii) the integration of the modules to ensure their functionality; (iii) the resources that will be needed to achieve this functionality and (iv) the technical/research methodologies that will be taken into consideration.

To this end, and based on a model of iterative development, the roadmap includes:

I. A high level view of the envisioned Platform architecture, illustrating the conceptual architecture.
II. A description of the functionality of each of the technical modules, describing: a. A summary of its scientific and technical objectives, and supporting technologies; b. Its progressively increasing functionality over time; c. Its timeline, detailing schedule and resource allocation;
III. The system integration
IV. A comprehensive description of the proposed pilot use cases with the motivation and scenario per pilot use case;
V. A global project timeline, describing the platform's scheduled iterations and the levels of functionality at the project milestones;

Therefore this deliverable is structured as follows. Section 2 presents the architecture in high level schema, while section 3 provides the functional description of the modules involved in accordance with the project workpackages (WPs). Then, section 4 presents the system integration. In Section 5, the development cycle and the pilot use cases are presented and finally section 6 provides the overall project timeline and the milestones. Section 7 concludes the deliverable.

2 MindSpaces Architecture High-Level Schema Foreseen in the DoA

In this section the initial architecture of MindSpaces platform is presented. This architecture is defined in a high-level schema foreseen in the DoA. The first draft of the MindSpaces architecture was developed before the kick-off of the project. It was the outcome from the efforts during the creation of the project proposal aiming to leverage the technical knowledge of the partners into a single and innovative platform.

2.1 Description

The technological objectives of the MindSpaces project and the technical background of the partners in the related fields of the project define a set of components, services and activities. Future possibilities and innovative elements are considered in the initial architecture plan described in the DoA. Based on the early concept of MindSpaces architecture, the project proposal, and the technical objectives, the defined MindSpaces components/activities could be grouped into the following categories:

Table 1 MindSpaces components/activities grouped into categories

Category	Description	Owner(s)
Data Collection from Sensors (WP3)	This group involves: i) the physiological data collection service/activity to collect EEG, GSR and HR from biosensors (T3.1) ii) the collection of visual data from video cameras for behavioural analysis (T3.2); iii) the space sensing tools for the collection of data for 3D reconstruction of indoor and outdoor spaces (T3.3 – T3.4); iv) Crawlers/Scrapers for the collection of data from Social Media, Blogs and Webpages (T3.5).	CERTH, U2M
Analysis of the offline collected data (WP4)	This group includes: i) the tools for the 3D-reconstruction of urban and indoors spaces (T4.1); ii) the Aesthetics and style extraction modules from visual content (T4.2); and iii) the text analysis component for the analysis of textual contents from Crawlers/Scrapers (T4.3).	U2M, CERTH, UPF
Analysis for the online adaptation of environments (WP5)	This group includes: i) The Emotion extraction based on physiological signals (T5.1); ii) The Human behaviour	MU, CERTH, UPF, U2M

	analysis from visual signals (T5.2); iii) Semantics (T5.3 – T5.4); iv) Text generation (T5.5); and v) Methodologies to parameterize 3D models of indoor and outdoor spaces (T5.6).	
Development of MindSpaces User tools AND System Integration	This group involves: i) the 3D tool for architecture design (T6.2); ii) the tool for adaptive VR environment (T6.3); and iii) System Integration (T6.4).	MCNEEL, NURO

MindSpaces is a platform aiming to provide solutions for adaptive and inclusive spaces that dynamically adapt to emotional, aesthetical and societal responses of end users, creating functionally and emotionally appealing designs for indoor and outdoor spaces. MindSpaces leverages multimodal data from different sensing environments. Multimedia content such as images, videos and texts will be acquired from different services of the system. These multimedia datasets in a raw form will be collected from sensors such as video cameras, physiological sensors and crawlers/scrapers.

Intelligent services will analyse and process this information having as a goal to extract valuable assets. These assets will be leveraged in order to generate new insights, which will be integrated through a semantics engine into innovative and intelligent design tools aiming to enhance and enrich the creative phase of designing outdoor/indoor spaces.

The MindSpaces components differ in several aspects such as data formats, functioning, and technology frameworks. The MindSpaces partners will cooperate to implement an innovative design tool mixed with elements from science, technology and arts having as a goal to fulfil the MindSpaces's objectives. Data from available online libraries and repositories and free available content on the web will be collected, transformed and processed.

The proposed and innovative system is built upon the concept of semantic integration of heterogeneous multimedia aiming to generate enhanced dynamic 3D structures and environments.

This semantic knowledge will act as complementary material for the design process of outdoor and indoor spaces. Architects, designers and artists will use MindSpaces platform to propose new designs for indoor and outdoor spaces. The end users will have the opportunity to experience these places in a VR environment and provide their feedback indirectly through the emotion extraction service from the analysis of physiological signals.

In the following figure, the MindSpaces architecture is presented in high-level schema. Figure 1 illustrates the MindSpaces components from various work-packages. MindSpaces development involves service-oriented architecture (SOA). The main challenges will be to meet the requirements and ensure the seamless integration of the modules developed from various WPs. Section 4 describes in more details the System Integration methodology.

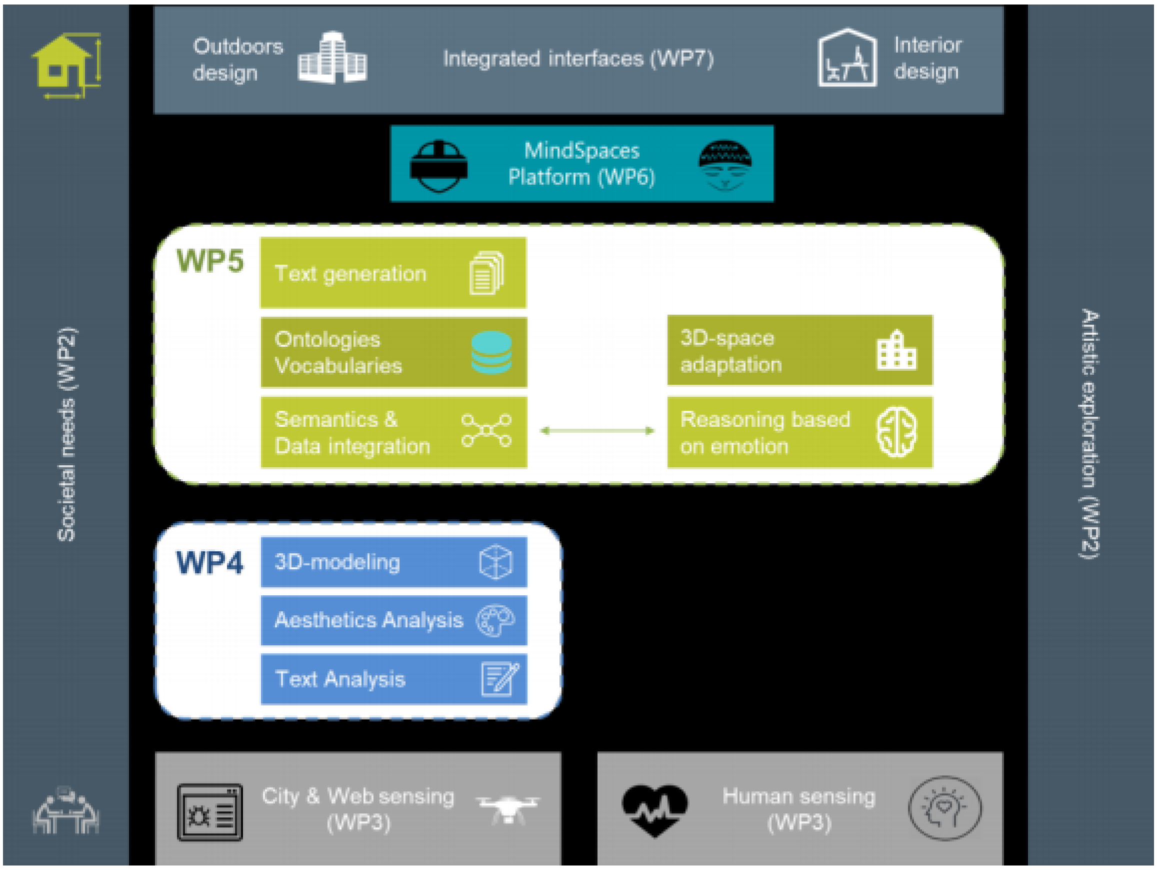

Figure 1. MindSpaces Architecture in high-level schema described in DoA.

2.2 Technology stack

A controlled set of technologies will be employed to implement the MindSpaces components, having as a goal to provide a robust, maintainable and manageable system. The technology stack that will be employed has to be defined by taking into consideration the compatibility between the system components. Although, the MindSpaces platform includes independent components there are dependencies for a subset of modules which impose the use of a certain technology. The technology stack could determine the success of a project and there are a couple of aspects that have to be taken into account. Sometimes, the selection of the technology stack is determined by the type of a module that you aim to build. For example, it is well-known that Python is an effective and powerful language for Machine Learning and Big Data services. In the following sections a list of the utilized programming languages, databases, technologies and exchange formats are presented.

2.2.1 Programming languages

A preliminary list of the selected programming languages for module implementation is provided in Table 2.

Table 2 Programming Languages

LANGUAGE/FRAMEWORK	VERSIONS ALLOWED	NOTES
Python	3.7	For scripting, and lightweight services.
Java	1.8	For scripting, and lightweight services.

2.2.2 Databases/Repositories

Table 3 includes a preliminary list of selected database/storage solutions.

Table 3 Database and Repository packages

DATABASE	VERSIONS ALLOWED	NOTES
MongoDB	2.4.x	For fast, non-relational storage
GraphDB		Non-relational triple store

2.2.3 Other technologies

A preliminary list of technological packages is provided in the following Table.

Table 4 Other Technologies

PRODUCT	VERSIONS ALLOWED	NOTES
OpenCvSharp3	4.0.0.20181129	Interface for Video Cameras for creating video files
OpenCvPython	4.1.0.25	For Aesthetics Extraction and Style Transfer
Tensorflow	2.0.0-alpha0	Computer Vision

2.2.4 Exchange formats

UTF-8 encoding [1] will be used and enforced throughout the platform to ensure correct and consistent handling of multilingual content.

The preferred exchange format for structured data will be **JSON**. For tools and/or modules, which do not support JSON, or when deemed appropriate, **XML** will also be used.

JSON-LD7 will be used where appropriate to represent linked data.

For the data from video cameras the **H.264** and **MJPEG** video formats are supported.

3 FUNCTIONAL DESCRIPTION OF MODULES

3.1 SENSOR DATA COLLECTION SERVICES AND TOOLS (WP3)

The sensor data collection services and tools are the means to collect the data required for high sophisticated services, aiming to inspire architects and artists to provide their designs and art installations.

3.1.1 DATA COLLECTION FOR EMOTIONAL AND COGNITIVE SENSING

This module is a data collection service. It involves one component with different inputs and outputs. This service uses lightweight recording devices that can capture EEG and physiological signals of a person while experiencing the various MindSpaces installations. The data collection for emotional and cognitive sensing component is undertaken under the task T3.1 and analysed and described thoroughly below:

The data collection for emotional and cognitive sensing service (BSDCS) aims to extract electroencephalogram[1] (EEG) and physiological signals (Galvanic Skin Response[2] (GSR) and Heart Rate (HR)) in order to measure the emotional and cognitive responses of the end users experiencing the various MindSpaces art installations, in order to assess their impact and effectiveness. EEG and physiological signals will be acquired from lightweight recording devices (such as Emotiv[3], Enobio [4]or Looxidvr[5]) incorporated with a VR headset if necessary. Participants will wear the aforementioned devices and experience the VR installations while gathering their physiological measurements.

The BSDCS extracts EEG and physiological signals from users experiencing the various MindSpaces art installations. This information will be used to recognize the emotional states of the users. Various studies have been using physiological signals in order to recognize the emotional states of the users since they are related to higher – level cognitive processes, including emotions [2], [3].

EEG, GSR and HR will be used to sense emotional and cognitive status of users while experiencing VR art installations in order to avoid noise artefacts, which appear in the presence of physical activity. The signals acquired synchronously from these sensors will act in a complementary fashion, leading to more accurate emotion detection rates.

Having in mind the anticipated differences in the sampling rates of the employed biosensors, an appropriate approach to universal bio signal timestamping will be applied that will allow each of the aforementioned signals to operate in their native sampling frequency.

In MindSpaces our methodology comprises the combination of multiple physiological signals in order to extract information about a person’s emotional state [4]. Our intention is to extract physiological signals while users are experiencing a virtual reality environment.

The properties of the BSDCS component are included in the following Table.

[1] https://www.mayoclinic.org/tests-procedures/eeg/about/pac-20393875
[2] https://www.media.mit.edu/galvactivator/faq.html
[3] https://www.emotiv.com/
[4] https://www.neuroelectrics.com/products/enobio/
[5] https://looxidlabs.com/looxidvr/

Table 5 BSDCS Summary

INPUT(S)	Bio-sensors from lightweight recording devices
OUTPUT(S)	Bio-signals (EEG, GSR, HR)
PROGRAMMING LANGUAGES/TOOLS	Python, Matlab
INTEGRATION	This service will communicate with a local storage service responsible for the processing and temporary storing of signals, while it will also communicate with a data storage service for general storing of bio signals. It is an offline service.
DEPENDENCIES	VR Tool
CRITICAL FACTORS	-

Figure 2 shows an example of extraction of EEG and physiological signals through recording devices and the produced output. Recording devices will extract EEG and physiological signals and these signals will be transferred in processing unit in recording devices' format (.xdf or .lx) or the csv format. The output of this service will be the collected bio signals from the recording devices.

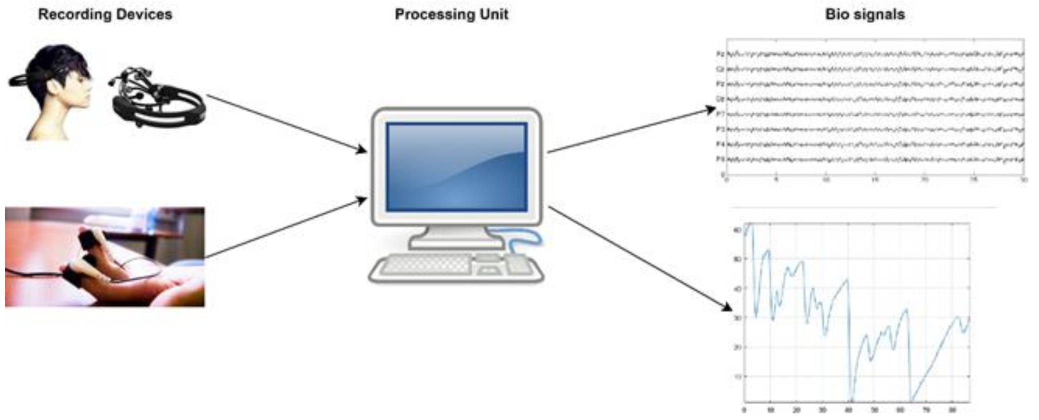

Figure 2. Overview of the BSDCS architecture

The logical design of the model is presented in Figure 3. Bio Signals Data Collection service will receive a message of activation/deactivation from Emotion Extraction service in order to start (or stop) collecting signals. The service will then start/stop recording signals through the recording devices that will also transfer the signals in the Bio signals Processing Unit of the service for local storage. BSDCS will also transfer the signals on the FTP server for final storage. On FTP server, signals will be available for use for BSDCS and any other service of MindSpaces. After collecting the signals, BSDCS will send a message to the Emotion Extraction service that signals have been collected. BSDCS will be also able to send the collected signals to Emotion Extraction service.

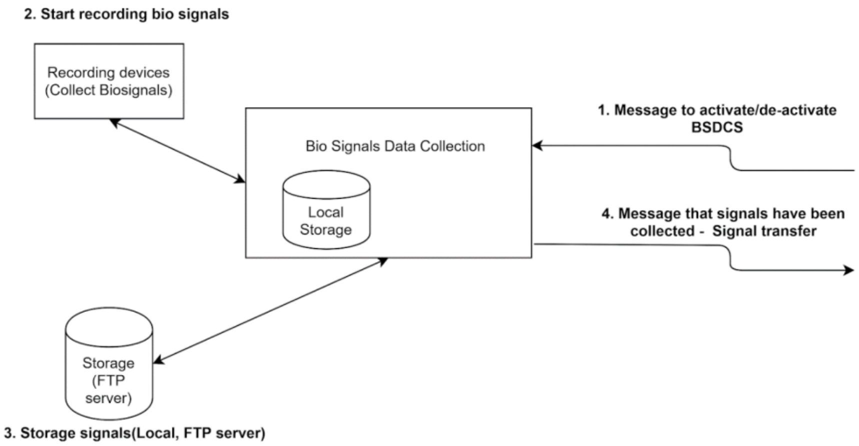

Figure 3. The Logical Design of the BSDCS.

Development milestones: This service is not under development yet, the respective task begins in M7 with expected delivery according to the following milestones:

- [M17]: Report the basic techniques that have been used during the first months of the project to collect data for the implementation of MindSpaces use cases. Basic techniques include data collection of EEG and physiological signals (GSR, HR) of the designed experimental protocols in the VR environment. Basic data collection techniques (V1) include initial records of pure signals and do not consist of artefact removal or preprocessing of signals.
- [M32]: Report the advanced techniques for EEG and physiological sensing used to assess the emotional and cognitive state of the end users. Advanced techniques will be more complicated recording techniques and will collect EEG and physiological signals while users will interact in the experimental protocols in the VR environment. These techniques will be evolved depending on the needs occurred from basic techniques (V1) and will include, if needed, artefact removal, subsampling techniques and fusion between EEG, GSR and HR signals.

3.1.2 DATA COLLECTION FOR VISUAL BEHAVIOUR ANALYSIS

The data collection for visual behaviour analysis involves the creation of the interface as a service for the communication with the visual equipment and the collection of video data from indoor and outdoor spaces. It is undertaken under the task T3.2. For the outdoor case, professional surveillance video cameras will be utilized. For the indoor cases additionally, a depth camera will be used for close-range human capture and interaction.

The visual data collection service for behavioural analysis (**VDCSBA)** will receive video frames from a set of installed wired video cameras. The video cameras will be IP video cameras connected into a local network. Several batches of video files will be recorded taking into account the duration, the type of compression and the fps. The data collected from visual sensors have to be forward to the relevant service for Visual Behaviour Analysis. Video processing is a computational expensive process and thus, it is decided to have both the data collection and the Visual Behaviour Analysis component running on the same machine.

The objective of the data collection for visual behaviour analysis is to utilize video cameras and record the end users' reactions in outdoor or indoor spaces. Videos will be recorded for behaviour assessment, activity recognition and event detection. Video cameras will provide anonymized data.

In outdoor spaces, video cameras will record locations to monitor crowd behaviours aiming to understand behaviours, activities and detect unusual events, such as the aggregation of many people in a specific location, or bottlenecks.

In indoor spaces, visual data could provide indicators of flow in a workspace or home interior, detect bottlenecks, more convenient routes and assess levels of interaction and activity. The analysis of video data will also reveal the functionality of outdoors and indoors environments, as it can show the flow in them, and possible bottlenecks that may arise, helping the development of more effective design solutions. Comparisons will take place with video analysis of the original locations, to demonstrate improvements brought on by the proposed designs.

The data collection for visual behaviour analysis involves the collection of data from indoor and outdoor spaces. Three different cases will be supported and different types of events, activities will be recorded. Workplaces, outdoor spaces such as public squares/areas and indoor places for elder people will be examined. The related equipment for the video data collection includes devices with the following specifications:

- Outdoor professional surveillance network video cameras, which support wired connection, night vision, maximum video resolution 1080p up to 30 fps, and video formats such as H.264.
- Indoor network cameras, with wired connection, maximum video resolution 1080p up to 30 fps, night vision and video formats such as H.264.
- Depth camera for the creation of advanced computer vision models by leveraging close-range human capture and interaction.

The properties of the visual data collection module are included in the following Table.

Table 6 VDCSBA Summary

INPUT(S)	Input from Video Cameras – Video Frames
OUTPUT(S)	Video Files (.mp4)
PROGRAMMING LANGUAGES/TOOLS	C# - .NET CORE
INTEGRATION	This service communicates with the installed and registered video cameras and creates the video files which are stored: a) locally for further processing and in an ftp server for general storing of video files.
DEPENDENCIES	-
CRITICAL FACTORS	-

Development milestones:

- [M17]: Initial data collection (V1) from video cameras. A set of records will be created aiming to collect the appropriate data for Visual Behavior Analysis. Different scenarios will be considered to capture the basic activities and events in spaces under study.
- [M32]: New datasets with video files describing the behavior of individuals while they experience the placed art installations. This dataset will include different levels of activity and social interaction. The second version (V2) will provide new data for the support of the advanced techniques for visual behavior analysis. Different events or activities of individuals could be presented and recorded from the spaces under study. Annotations could also be included and preprocessing techniques could also be applied to the raw video files.

3.1.3 SPACE SENSING FOR 3D RECONSTRUCTION OF OUTDOOR ENVIRONMENT

This activity is undertaken under the task T3.3. U2M will set up the scanning of the outdoors environment with the use of drones and a custom-built mobile mapping platform, in order to produce 3D-models of the urban environment. Commercial quadcopters, equipped with high-resolution cameras on gimbals, will be used to conduct aerial campaigns. Flights will be organized at different areas of interest to generate photogrammetric 3D textured models. Through mission planning, optimal flight plans will be designed to ensure that each world point will be depicted in multiple image frames. Video sequences and still images will be captured at constant time intervals to guarantee high overlaps. Missions for vertical image acquisition will capture the terrain and building roofs, while separate flights for oblique imagery will optimally record building facades. GPS sensors on board the UAVs will support image orientations in 3D space. Additionally, U2M will build a custom mobile mapping platform to capture street level imagery and 3D data. The system will consist of several RGB cameras equipped with suitable wide angle (e.g. fish-lenses), a GPS/IMU sensor and a low-cost lidar sensor (such as velodyne[6]). The whole system will be mounted on a car. Several data capture missions will be carried out to enrich and complete the drone campaigns, ensuring the acquisition of imagery and range data from all possible scene directions. Table 7 presents a summary of space sensing for 3D reconstruction of outdoor environment. The overview of the mobile mapping platform for sensing outdoor spaces is illustrated in Figure 4.

Objectives:

- Record images, point clouds, location and relevant data

Methodology:

- Optimal mission planning to ensure the necessary spatial, temporal and radiometric resolution of initial data.
- Vertical and oblique aerial imagery
- Custom mobile mapping platform for images, lidar data, GPS / IMU data

Expected results

- Data of aerial and ground images, geolocations, point clouds, inertial info
- Data from terrestrial laser scanner with basic photo-texture

[6] https://velodynelidar.com/

Table 7 Summary of space sensing for 3D reconstruction of outdoor environment

INPUT(S)	Sensors: cameras, GNSS, IMU, scanner
OUTPUT(S)	4x4K sync video frames, position and inertial data, point cloud, stereo video
PROGRAMMING LANGUAGES/TOOLS	Python, C++, Java
INTEGRATION	This service will communicate with an online storage service responsible for backing up and organizing the data. Preprocessing of the data and manual annotation will also be online. The service will communicate A) with a local server in house for the processing and temporary storing of data; B) with the MindSpaces VR platform to have the data available for the artists. These are offline services and processes with respect to the MindSpaces platform.
DEPENDENCIES	Processing algorithms T4.1, VR platform
CRITICAL FACTORS	-

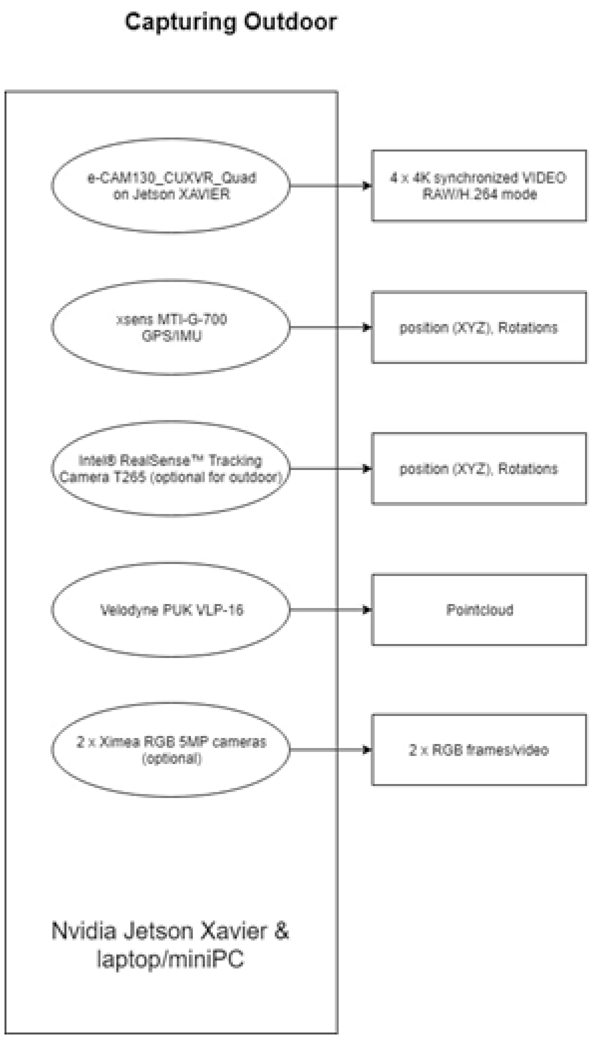

Figure 4. Overview of the mobile mapping platform for sensing outdoors

According to DoA, the space sensing for 3D reconstruction of Outdoor environment is involved in the following technological objectives and activities of the MindSpaces project. The related Key Results are also presented below.

Technological Objective and Activity

TO1. Data collection

TA1.3. Visual data collection: This activity includes planning and execution of data capture indoors and outdoors for 3D-reconstruction purposes, as well as depth images from RGB-D cameras to implement behavior analysis.

Key Results

KR13. Visual data, point clouds from laser scanner and depth images [TRL 7 to 8]: MindSpaces will use *industrial tools* [7][8][9]to acquire visual data, point clouds and depth images from interior and exterior environments. MindSpaces foresees to bring an *improvement* on the use of these technologies and set them up to be *deployed in real case scenarios*.

KR14. Agile system architecture [TRL 3 to 7]: Currently there is no product combining all the services foreseen by MindSpaces. The integration of these services in a common platform and testing them in an operational environment in 3 realistic use cases is expected to bring the *technology readiness of the platform close to 6 or 7*.

Figure 5 shows raw results from Mobile Platform, Scanner and Drone.

Figure 5. Expected Raw Results of the Mobile Platform, the Scanner and the Drone

Development milestones: The development of the data acquisition platform has not officially started yet. The related task -T3.3 is starting, according to the overall schedule, at M7. It lasts till M18 and then there is a 2nd acquisition platform development phase from M27 to M34 to redevelop, correct and refine the platform according to the feedback from the MindSpaces platform. This said, up2metric has already started compiling the system by selecting the appropriate equipment and hardware based on the preliminary user and technical requirements, setting and integrating the hardware and testing open source and proprietary in house s/w. The corresponding milestones are as follows:

- [M8]: State-of-the-art and commercial systems review (SoA-R), it will be included in the D3.1.
- [M18]: Mobile mapping platform development (MMPD)

[7] https://www.faro.com/products/construction-bim-cim/faro-focus/
[8] https://structure.io/
[9] https://store.stereolabs.com/products/zed/

- [M18], [M30]: Data collection (DC)
- [M28]: Mobile mapping platform adjustments (MMPA)
- [M34]: Systems refinement (SR)

3.1.4 INTERIORS SENSING FOR 3D RECONSTRUCTION

This activity is undertaken in task T3.4. A terrestrial laser scanner, such as the FARO Focus 3D phase-shift laser scanner[7], is going to be utilized in order to create the 3D-model of interior spaces. For smaller interior design objects like decorations, small furniture, artwork etc. U2M is going to employ a custom built structured light 3D scanner. Multiple scans from different viewpoints are required to capture the 3D environment. It must be noted, that although 3D scanners are capable of capturing 3D point clouds in high precision there will be unrecorded areas mainly due to surface occlusions and areas where it is not possible to place a 3D scanner. To overcome this, U2M will also develop a custom 3D acquisition platform based on off-the-shelf RGB cameras, suitable panoramic lenses and low-cost depth sensors (such as structure.io, ZED camera) in order to facilitate the 3D recording of complex indoor environments. A calibration and mutual registration of all cameras and sensors will be performed and a custom software solution will be developed for photorealistic 3D reconstruction from all acquired data. The proposed solution utilizes commercial hardware and existing software libraries, such as COLMAP [10]and ORB-SLAM2 [11]for monocular, stereo and RGB-D sensors and U2M structured light scanner library and will combine these in an optimization algorithm to a dedicated product. The overview of the mobile mapping platform for sensing indoor spaces is illustrated in Figure 6. Table 8 presents a summary of space sensing for 3D reconstruction of indoor environment. Figure 7 shows the overview of structured light system for detailed artifacts.

Objectives:

- Visual, range, location, inertial data for reconstructing photorealistic 3D models of indoor scenes

Methodology:

- Terrestrial 3D scanning
- Custom static structured light scanning for detailed artifacts
- Mobile acquisition platform
- Stereo and panoramic cameras
- Range and depth sensors
- IMU
- On-board processing unit
  - Field storage
  - Fusion of multi-modal data (calibration & co-registration)

Expected results:

- Synchronized spatio-temporal dataset of images and point clouds
- Terrestrial laser scanner data
- Structured light data of small artifacts if needed from the artists and architects

[10] https://colmap.github.io/
[11] https://github.com/raulmur/ORB_SLAM2

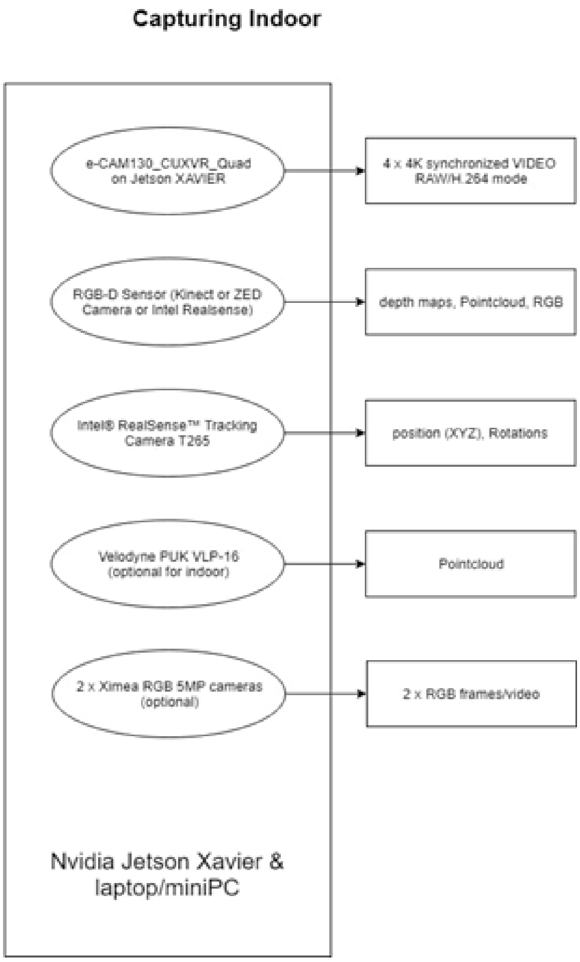

Figure 6. Overview of the mobile mapping platform for sensing indoors

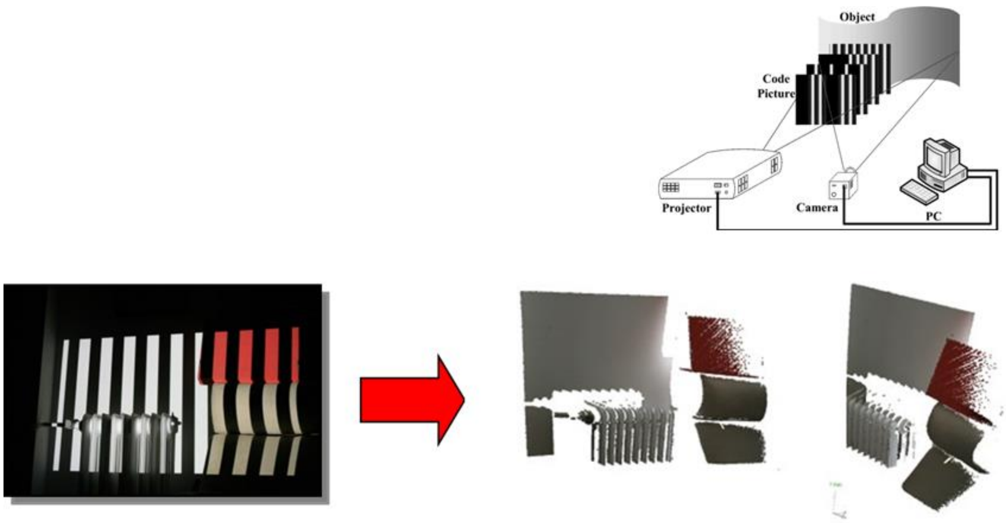

Figure 7. Overview of Structured Light system for Detailed Artifacts

Table 8 Summary of space sensing for 3D reconstruction of indoor environment

INPUT(S)	Sensors: cameras, ego-motion sensor, IMU, scanner
OUTPUT(S)	4x4K sync video frames, position and inertial data, point cloud, stereo video

Programming Languages/Tools	Python, C++, Java
Integration	This service will communicate with an online storage service responsible for backing up and organizing the data. Preprocessing of the data and manual annotation will also be online. The service will communicate A) with a local server in house for the processing and temporary storing of data; B) with the MindSpaces VR platform to have the data available for the artists. These are offline services and processes with respect to the MindSpaces platform.
Dependencies	Processing algorithms T4.1, VR platform
Critical Factors	-

Figure 8 presents an example of point cloud of Interior Spaces. In Figure 9 Point Cloud with Photo Texture is illustrated.

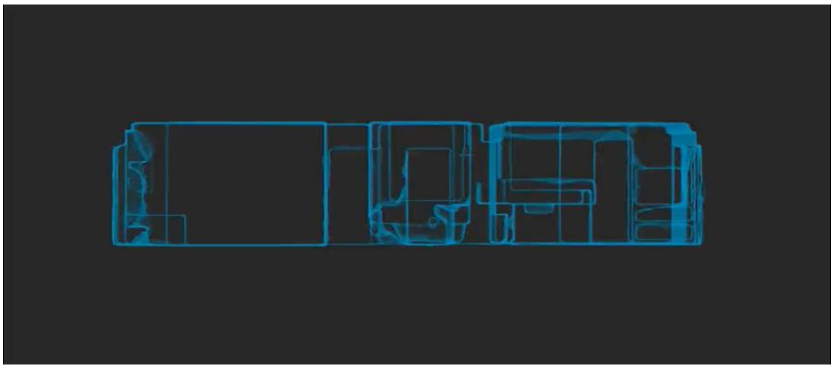

Figure 8. Point Cloud of Interior Spaces

Figure 9. Point Cloud with Photo Texture of Interior Spaces

The Technological Objectives and Activities of the Interiors Sensing for 3D Reconstruction process are similar to the Space sensing for 3D reconstruction of outdoor spaces, the differences lie at the data capturing platform and at the processing algorithms. The related technological objectives, activities and Key Results are presented below.

Technological Objective and Activity

TO1. Data collection

TA1.3. Visual data collection: This activity includes planning and execution of data capture indoors and outdoors for 3D-reconstruction purposes, as well as depth images from RGB-D cameras to implement behavior analysis.

Key Results

KR13. Visual data, point clouds from laser scanner and depth images: MindSpaces will use *industrial tools* to acquire visual data, point clouds and depth images from interior and exterior environments. MindSpaces foresees to bring an *improvement* on the use of these technologies and set them up to be *deployed in real case scenarios*.

KR14. Agile system architecture: Currently there is no product combining all the services foreseen by MindSpaces. The integration of these services in a common platform and testing them in an operational environment in 3 realistic use cases is expected to bring the *technology readiness of the platform close to 6 or 7*.

Development milestones: The development of the data acquisition platform has not officially started yet. The related task T3.4 is starting, according to the overall schedule, at M7. It lasts till M18 and then there is a 2nd acquisition platform development phase from M27 to M34 to redevelop, correct and refine the platform according to the feedback from the MindSpaces platform. This said, up2metric has already started compiling the system by selecting the appropriate equipment and hardware based on the preliminary user and technical requirements, setting and integrating the hardware and testing open source and proprietary in house s/w. The corresponding milestones are as follows:

- [M8]: State-of-the-art and commercial systems review (SoA-R), it will be included in D3.1.
- [M18]: Indoor scanning system development (ISS-V1)
- [M18]: Structured light system development (SLS-V1)
- [M18], [M30]: Data collection (DC)
- [M28]: Indoor scanning system development (ISS-V2)
- [M28]: Structured light system development (SLS-V2)
- [M34]: Systems refinement (SR)

3.1.5 CRAWLERS-SCRAPERS FOR DATA COLLECTION FROM SOCIAL MEDIA/WEB

The social media and web data crawling/scrapping service is responsible for extracting freely available textual and visual content from open web resources, including social media. Different types of mechanisms will be deployed that will accommodate for different categories of sources, such as social media providing APIs which will be wrapped around by the development of this service (e.g. Facebook, Twitter, YouTube, Instagram, Pinterest), online media where a combination of crawling and scraping techniques will be adopted (e.g. blogs, web pages) and visual artworks (e.g. Google Cultural Institute, Tate Archive, Europeana Foundation). Concluding, all the mechanisms mentioned above will gather material based on the automatic construction of suitable queries based on machine learning techniques. This service is undertaken under the task T3.5. Table 9 presents a summary of the Crawling/Scraping service.

Table 9 Crawling/Scraping service Summary

INPUT(S)	Text and multimedia content
OUTPUT(S)	Json serialization of harvested items
PROGRAMMING LANGUAGES/TOOLS	Java, Python
INTEGRATION	This service will communicate exclusively with a data storage service responsible to save aggregated online content. It will work periodically.
DEPENDENCIES	selection of sources to be processed by the crawlers
CRITICAL FACTORS	Source selection: selection of sources for multimedia should be relevant to the problem domains defined in the UCs and be updated regularly. Outdated, incorrect or irrelevant data can compromise the quality of the results of the Mindspaces processes.

The logical design of the crawler service is shown in Figure 10. The service consists of several different components with various data input and output, responsible for multiple functions performed. The aim of the web crawling component is to discover which nodes are about to be scrapped and receives as input web entry points. The query expansion component is connected in a serial pipeline with the web and social media search component in a way that the first receives queries in the form of keywords and provides extended versions of the queries to the second component, by finding extra keywords relevant to the input query, which in turn enriches the discovered resources with nodes, possibly containing content also. The later component depends mainly on the available APIs, enabling also the procedure of scrapping. The scrapping procedure involves two different types of web input, websites as well as social media. In the case of web content, the component receives web resource URLs extracting their content that may be textual or visual. In the occasion of social media, the equivalent component extracts content from hashtags, user accounts, etc. and delivers social media posts. Finally, the resource filtering component is responsible for the application of classifiers that categorize the resources as appropriate or not for the purpose of the project, receiving as input all the information aggregated from the web and delivering a suitable subset of it to the content database.

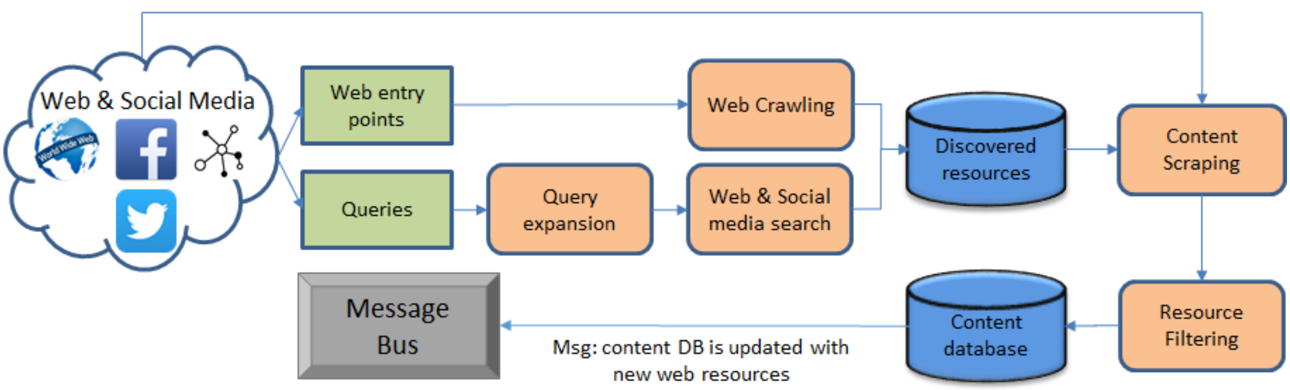

Figure 10. The logical design of social media and web data crawling/scrapping service

Development milestones:

- [M06]: The foundational infrastructure of the service will be implemented, e.g. a dummy service (DS) capable of contacting bidirectionally the message bus, without any further functionalities.
- [M12]: Basic version (BV) of crawling/scrapping functionality will be available as we move forward towards V1. This involves the development of the algorithms responsible for gathering data from heterogeneous sources.
- [M20]: Crawling/Scrapping functionality aiming to fulfil the V1 requirements. The algorithms in M20 will extend the ones developed in M12, taking into consideration updates and refinements made in the MindSpaces modules to address the technical and user requirements. To this moment, the service will be able to provide real data to the system, gathered from various sources suggested by UPF, MoBen.
- [M28]: Vital updates will be available towards V2, based on the evaluation of V1. Machine learning techniques will be investigated on how to provide more sophisticated formulation of queries. At this point, a refined version (RV) will be developed.
- [M34]: Vital improvements on the final system, according to the updates made to the other components. In the final version (V2) the focus will be also given on the robustness of the algorithms as well as on developing strategies when the information from sources is incomplete.

3.1.6 TIMELINE AND DEPENDENCY FROM OTHER MODULES

Table 10 WP3 Timeline

															D3.1															D3.2, D3.3, D3.4				
WP3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. Data Collection for Emotional and Cognitive Sensing															V1															V2				
2. Data Collection for Visual Behaviour Analysis															V1															V2				
3. Space Sensing for 3D Reconstruction of Outdoor Environment						SoA-R										MMPD, MMPA, DC												DC				SR		
State-of-the-art and commercial systems review																																		
Mobile mapping platform development																																		
Mobile mapping platform adjustments																																		
Data collection																																		
Systems refinement																																		
4. Interiors Sensing for 3D Reconstruction						SoA-R										ISS-V1, DC, SLS-V1										ISS-V2, SLS-V2		DC				SR		
State-of-the-art and commercial systems review																																		
Indoor scanning system development																																		
Structured light system development																																		
Data collection																																		
Systems refinement																																		
5. Crawlers/Scrapers for Data Collection from Social Media/Web				DS						BV								V1								RV						V2		

3.2 Analysis of Emotional, Cognitive and Environmental Sensing (WP4)

The objective of the services and tools described in this section, is to analyse the produced offline data created from sensors. New insights will be provided and the extracted information will be aggregated to build the Knowledge Base of the system.

3.2.1 3D-reconstruction of urban and indoors space

U2M will exploit image data from drones and a mobile mapping platform and data from a terrestrial laser scanner, a structured light scanner and a custom-built 3D acquisition platform in order to provide high fidelity 3D models of urban and indoor spaces. The presented workflow combines custom SfM, SLAM and stereo-matching algorithms, commercial and open-source tools. The 3D reconstruction of urban and indoors space is undertaken under the task T4.1. Concerning the urban outdoors spaces, aerial imagery from the drone flight missions will be combined with street level images from the mobile mapping platform in order to create photorealistic 3D mesh models of high visual and geometric accuracy. For this, the drone and the mobile mapping cameras will be calibrated, all images will be oriented and dense 3D point clouds will be reconstructed with an automated Structure-From-Motion (SFM) approach. Concerning the 3D modelling of indoor spaces U2M will combine data from a terrestrial laser scanner and data from a custom-built 3D sensing platform. The workflow consists of mutual registration, mesh model creation and photo-texturing of the models via the available image data. For small individual objects, a structured light scanner will also be used. Structured light scanning relies on the projection of different light patterns on 3D object surfaces. Automatic pattern identification on images allows reconstructing both the shape and the appearance of the recorded 3D objects. In parallel to the above methodology, single image 3D reconstruction techniques that employ vanishing points and prior knowledge on objects geometry are going to be applied in paintings and 2D images, to build a 3D-model database that will contain interior design objects from the past. All the 3D mesh models will be provided in suitable formats for use in Virtual and Augmented Reality apps for the creation of immersive 3D experiences and in CAD/CAM software such as Rhino/Grasshopper.

Objectives:

- Produce photo-textured models of variant resolutions depending on the needs of adaptive design

Methodology for mesh model reconstruction & photo-texturing (Research Objective RO2)

- Fusion of aerial photogrammetry and mobile mapping
- Fusion of terrestrial laser scanner, custom-built 3D sensing platform, structured light data
- Novel algorithms, established open-source and commercial s/w for:
  - **RA2.1 3D model extraction from archival visual material (3D from 2D)**
  - Structure from Motion for multiple images of the past, or videos
  - Single-view reconstruction of planar objects
  - Lines, vanishing points
  - Semantic info on the 3D models via DL
  - Exploit semantic for single-view reconstruction
  - User input for occlusions (semi-automatic process)
  - **RA2.2 3D reconstruction of outdoors environments**

- UAVs or mobile mapping systems
- all calibrated, oriented
- Structure-From-Motion, sparse multi-image point correspondences
- GPS
- self-calibrating bundle adjustment
- large differences among the poses of acquired images
- Multiple View Stereo - MVS
- 3D triangulation to 3D mesh
- photorealism via weighted blending scheme
- An end-to-end fully automated 3D model generation system from images for acquiring 3D information.
- **RA2.3 3D reconstruction of interior environments**
- a terrestrial laser scanner and data from a custom-built 3D sensing platform
- Structured light scanning
- registration of the individual scans a preliminary mesh model
- an automatic image and depth sensor orientation via a (SLAM) scheme
- a mutual registration of the scanner point cloud and the image data
- the production of the final unified mesh photo-texturing

Expected results:

- 3D models of
  - interior spaces
  - Urban spaces
  - Interior design objects of the past
- The 3D mesh models will be provided in suitable formats for use in Virtual and Augmented Reality apps for the creation of immersive 3D experiences and in CAD/CAM software such as Rhino/Grasshopper.

Table 11 presents a summary of 3D reconstruction of urban and indoors spaces. The related technological objectives, activities and Key Results of the MindSpaces project are followed.

Table 11 Summary of 3D reconstruction of urban and indoors spaces

INPUT(S)	4x4K sync video frames, position and inertial data, point cloud, stereo video
OUTPUT(S)	Textured 3D models
PROGRAMMING LANGUAGES/TOOLS	Python, C++, Java
INTEGRATION	The algorithms will run offline in local servers in U2M.
DEPENDENCIES	Capturing platforms of T3.2 & T3.3; T5.6
CRITICAL FACTORS	-

Research Objective and Activities

RO2. 3D model extraction

RA2.1. 3D model extraction from archival visual material (3D from 2D)

RA2.2. 3D reconstruction of outdoors environments

RA2.3. 3D reconstruction of interior environments

Key Results

KR4. 3D models of 2D objects and art elements: MindSpaces will use laboratory validated technologies so as to build benchmark 2D to 3D model extraction techniques and use them so as to move SoA forward and deploy robust algorithms that could function in real world settings.

KR5. Photorealistic 3D models of outdoor spaces: MindSpaces will extend image-based modelling by contributing in specific tasks such as point matching among images with large pose differences.

KR6. 3D mesh: MindSpaces, and U2M in particular, will create a *novel 3D sensing platform for indoor* with photorealistic texture of indoor spaces mapping, while simultaneously develop its core technologies, both hardware and software.

KR14. Agile system architecture: Currently there is no product combining all the services foreseen by MindSpaces. The integration of these services in a common platform and testing them in an operational environment in 3 realistic use cases is expected to bring the *technology readiness of the platform close to 6 or 7*.

Development milestones:

- [M6], [M23]: State-of-the-art and commercial systems review (SoA-R), it will be included in D4.1 and D4.2 respectively.
- [M9]: Systems' calibration (SC)
- [M18]: Basic Methods for indoor (IBM)
- [M18]: Basic Methods for urban (UBM)
- [M28]: Advanced Methods for indoor (IAM)
- [M28]: Advanced Methods for urban (UAM)
- [M33]: Fine tune algorithms and methods (FT)

3.2.2 AESTHETICS AND STYLE EXTRACTION FROM VISUAL CONTENT

This module is an image processing service. It is undertaken under the task T4.2. It involves two different components with different inputs and outputs. Both of them use machine-learning techniques for the representation of images. However, the first component deals with the classification of paintings and artworks while the second takes into consideration the visual features estimated from images aiming to extract the style of a selected painting or artwork and transferring it into another image for the creation of innovative works of art. These two components are analysed and described thoroughly below.

Aesthetic Extraction (AE): The Aesthetic Extraction (AE) aims to extract and categorize the aesthetics of paintings based on their style (i.e. impressionism, cubism and expressionism), creators and genre. This service will be used to categorize the acquired paintings and create an aesthetic gallery from where a designer could choose or be inspired from, in order to create novel architecture structures or other artworks. In the MindSpaces platform users will be able to search the database and retrieve paintings or images of artwork based on the supported search criteria such as aesthetic, style and genre.

The AE component extracts geometry, style and other aesthetics aspects from artwork collections. This information in the form of metadata will be forward to the MindSpaces platform. Visual features will be taken into consideration and measured, such as colour (RGB, HSV, etc.), texture, image bumps, gradients, palettes, and patterns.

Nowadays, aesthetic analysis is an increasingly appealing topic in computer vision and multimedia research community. The aesthetic extraction is formulated as a classification problem. The challenge of classifying paintings involves different studies with different classification criteria.

Most of the earlier studies take into consideration the classification of paintings based on style [5], artist [6] and genre [7]. These approaches are characterized by the use of a set of various visual features and the training of several classifiers such as support vector machines (SVM), multilayer perceptron (MLP) and random forests. The visual features employed for the representation of images commonly include low-level features related to shape, texture, edge and colour properties.

Recently, the challenging task of classification of paintings and images of artwork produced a significant progress caused by two parallel streams [8]: the appearance of large, well-annotated and openly available fine art datasets on one side; and significant advancements in computer vision related tasks achieved with the adoption of Convolutional Neural Networks on the other side.

CNNs were firstly examined as feature extractors for the representation of images with a vector of values. The first approach for using a CNN, trained on ImageNet database for object recognition on non-artistic images, for artistic style extraction/classification was introduced in [9]. It should be mentioned that in order to train a CNN from scratch a relatively large set of images is still considered a prerequisite.

In MindSpaces our methodology comprises the examination of multiple art collections. WikiArt[12], Web Gallery of Art (WGA[13]), Painting 91 [14]and museum-centric OmniART[15] are some of the datasets that will be taken into consideration. Moreover, our intention is to provide a new Aesthetic extraction technique, validating its performance by comparing classification results from the proposed method and the conventional existing techniques.

The properties of the AE component are included in the following Table. Figure 11 shows an example of a painting and the produced outputs from a trained model of the AE module. The logical design of the module is presented in Figure 12.

First, a request to extract the aesthetics from an image is received. The image is loaded from the DB and afterwards the processing phase takes place. The results related to the query image are then saved into the DB.

[12] https://www.wikiart.org/
[13] https://www.wga.hu/index1.html
[14] http://www.cat.uab.cat/~joost/painting91.html
[15] http://isis-data.science.uva.nl/strezoski/#2

Table 12. AE Summary

INPUT(S)	An ID of an image
OUTPUT(S)	The related Style, Creator, Genre
PROGRAMMING LANGUAGES/TOOLS	Python, Tensorflow
INTEGRATION	This service will communicate exclusively with a data storage service responsible to provide images for detecting attributes such as style, genre and creator.
DEPENDENCIES	-
CRITICAL FACTORS	The aesthetics extraction service is a classification model and its performance and application depends on the datasets used for training of the model.

Style: Post Impressionism

Genre: Still life

Artist: Vincent Van Gogh

Figure 11. A pair of shoes-Vincent Van Gogh, 1886

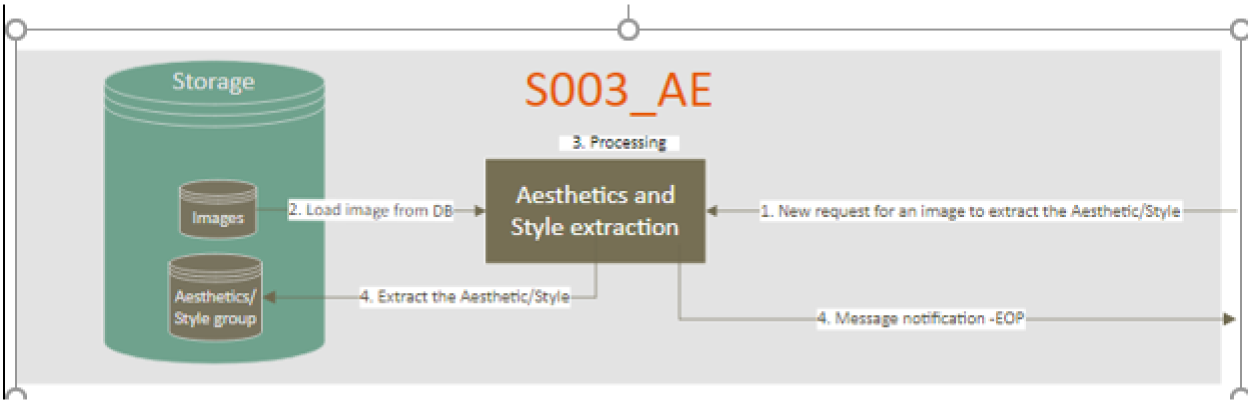

Figure 12. The Logical Design of the Module

Development milestones: This service is currently under development, with expected delivery according to the following milestones:

- [M12]: A basic version (BV) of aesthetics component is released. An existing technique will be employed for the operational prototype.
- [M15]: The 1st version (V1) of the aesthetics component will be delivered. This version includes the style, genre, and creators attributes.

- [M22]: Integration of the 2nd version (V2) in MindSpaces. Additional data will be included different classifiers will be tested and new attributes such as emotion or creator's nationality could be examined.
- [M33]: Final version (FV) will be deployed.

Texture Proposal (TP): from paintings and other artwork images. This module will leverage the categorized paintings, which are annotated from the AE component. The TP module transfers styles from categorized paintings and other artwork images. The new styles will be provided to architects and designers inspiring them to create novel 3D objects. More specifically a user provides a set of 2D images taken from the same object from different angles. Each 2D image will be processed offline and a style will be transferred. From the new set of the produced 2D images a 3D reconstruction of the object will take place allowing us to apply several different textures.

The challenge of texture proposal has its origin from non-photorealistic rendering [10], and is closely related to texture synthesis and transfer [11]. Some early approaches include histogram matching on linear filter responses [12] and non-parametric sampling [13]. These methods typically rely on low-level statistics and often fail to capture semantic structures. Gatys et al. [14] for the first time demonstrated impressive style transfer results by matching feature statistics in convolutional layers of a DNN. Recently, several improvements have been proposed. Gatys et al. [15] proposed ways to control the colour preservation, the spatial location, and the scale of style transfer.

In MindSpaces, our methodology similar to AE includes multiple art collections. WikiArt, Web Gallery of Art (WGA), Pandora dataset, Painting 91 and museum-centric OmniART are some of the datasets that will be taken into consideration. Our goal is to provide a new Texture Proposal/ Style transfer technique, validating its performance by comparing the experimental results from the proposed method and the conventional existing techniques.

The properties of the TP component are included in the following Table. Figure 13 illustrates examples with different pairs of inputs and the produced outputs for a set of different methodologies [16]. The logical design of the model is presented in Figure 14.

Figure 13. Examples of style transfer results

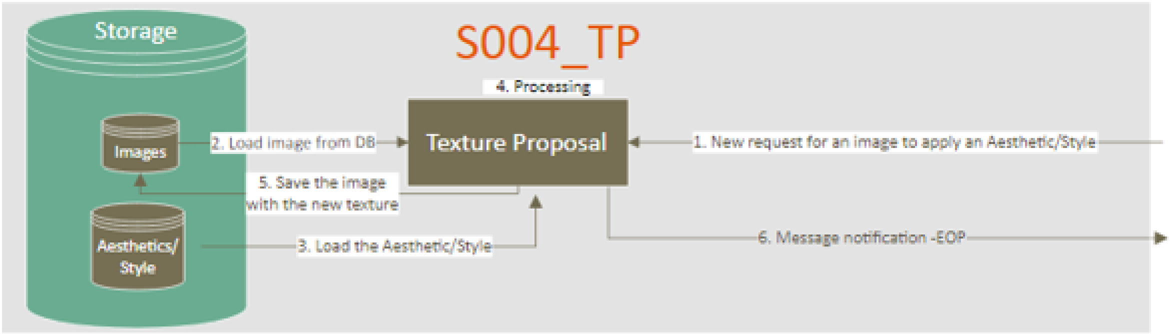

Figure 14. The Logical Design of the Module.

Table 13 TP Summary

INPUT(S)	Two IDs of images. The first is from the painting and the second for the tested image
OUTPUT(S)	A new image with a new id
PROGRAMMING LANGUAGES/TOOLS	Python, Tensorflow
INTEGRATION	This service will communicate exclusively with a data storage service responsible to provide images for applying the style transferring. It is an offline service.
DEPENDENCIES	N/A
CRITICAL FACTORS	The processing time

Development milestones: This service is currently under development, with expected delivery according to the following milestones:

- [M17]: The 1st version (V1) of the TP algorithm will be delivered.
- [M26]: The 2nd version of the TP (V2) will be deployed. The idea is to examine a feed-forward CNN that could capture multiple different styles by introducing conditional instance normalization.
- [M33]: Final version (FV) will be deployed.

3.2.3 TEXTUAL ANALYSIS

Textual Analysis (TA): The textual analysis service is undertaken under the task T4.3. It receives textual information (in any of the supported languages) and extracts linguistic and semantic information, including but not limited to concepts or entities appearing in the text, when possible with links to external knowledge resources such as DBpedia[16], and their relations. It also aims at identifying the most relevant / important parts of the text.

The extracted information can be used directly to visually represent the most "interesting" or relevant aspects of the input text(s), or it can be fed into a knowledge base for further processing or reasoning, potentially in combination with other information sources.

[16] https://wiki.dbpedia.org/

The service combines multilingual dependency parsers and lexical resources, and a projection of the extracted dependency-based linguistic representations into ontological ones. The analysis pipeline comprises the following sub-modules:

- Tokenization: identify the token boundaries;
- Part-of-speech tagging: assign grammatical categories to tokens (noun, verb, etc.);
- Lemmatization: determine base form of tokens (built -> build);
- Concept Extraction, Entity linking and Sense Disambiguation: assign particular senses or referents to tokens or groups of tokens;
- Surface-syntactic parsing: assign grammatical relations between tokens;
- Deep-syntactic parsing: assign predicate-argument relations between meaning-bearing tokens (first argument, second argument, etc.);
- Sentiment analysis: assign emotional labels to tokens or concepts;
- Conceptual relation extraction: map to language-independent abstract structures.

Starting from the input texts, representations of higher abstraction are successively obtained, until the underlying semantics are distilled in a formal and language-independent manner that allows for automated reasoning and interpretation.

The properties of the TA component are included in the following Table. The logical design of the model is presented in Figure 15.

Table 14 TA Summary

INPUT(S)	Plain text
OUTPUT(S)	extracted concepts, relations, and other linguistic or semantic information (JSON structure)
PROGRAMMING LANGUAGES/TOOLS	Java (UIMA), Python
INTEGRATION	This service will exchange data with the database / knowledge base of the system. It will connect to the message bus for receiving new requests for textual analysis.
DEPENDENCIES	Crawler Semantic Integration and Reasoning
CRITICAL FACTORS	The processing time: throughput varies based on pipeline configuration and document length, between ~10 seconds per document and several minutes per document (per computation node) Scalability: can scale horizontally by adding computing nodes

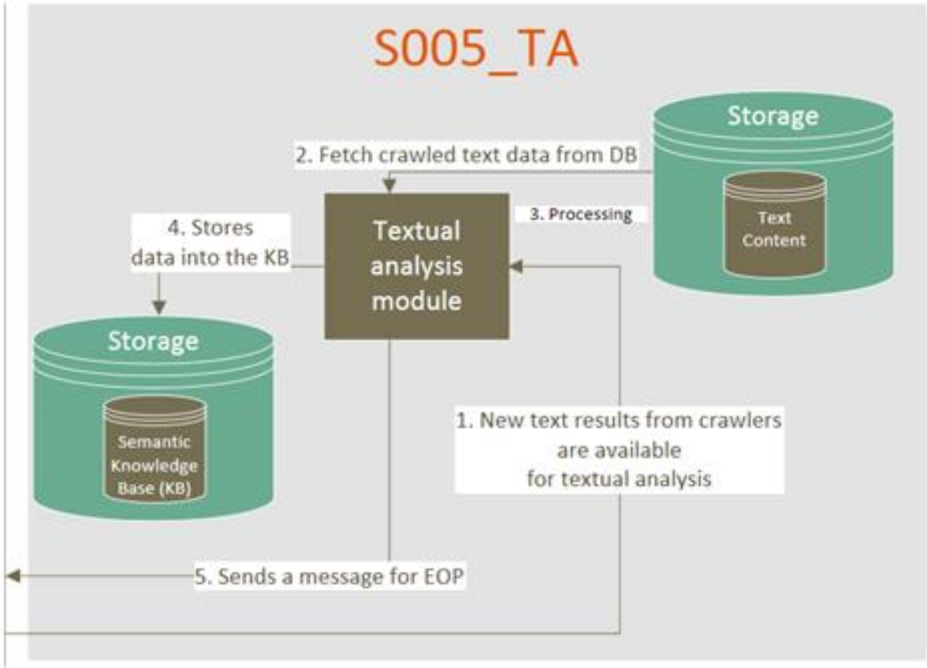

Figure 15. The Logical Design of the TA.

Development milestones: This component is currently in development, its expected milestones are the following:

- [M12]: Operational prototype (OP). The textual analysis pipeline will be able to output language-independent representations starting at least from English, for a limited set of input sentences.
- [M18]: The first version (V1) includes basic techniques for multilingual text analysis. The analysis pipeline will be operational for at least three languages with an improved coverage according to the specifications of the different UCs. The quality of the outputs will be evaluated.
- [M33]: The second version (V2) of multilingual text analysis. The analysis pipeline will have an improved coverage and will be able to handle all the languages of MindSpaces (English, Spanish, French, German, and Greek). The advanced tools necessary for textual analysis of archival material will be implemented. Efforts will be dedicated to ensure the reusability of the developed tools outside of MindSpaces.

3.2.4 TIMELINE AND DEPENDENCY FROM OTHER MODULES

Table 15 WP4 Timeline

														D4.1															D4.2, D4.3			
WP4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. 3D-Reconstruction of Urban and Indoors Space		SoA-R			SC									IBM-UBM					SoA-R					IAM-UAM					FT			
2. Aesthetics and Style Extraction from Visual Content																																
Aesthetic Extraction (AE)								BV			V1							V2											FV			
Texture Proposal (TP)													V1									V2							FV			
3. Textual Analysis (TA)								OP						V1															V2			
General linguistic analysis								OP						V1															V2			
Concept extraction								OP						V1															V2			
Semantic analysis								OP						V1															V2			

3.3 MindSpaces adaptive environment development (WP5)

3.3.1 Emotion extraction MODULE based on EEG and physiological signals

This module is an emotion extraction service based on EEG and physiological signals. It is undertaken under the task T5.1. It involves one component with different inputs and outputs. This service uses machine-learning classification techniques for the representation of EEG and physiological signals in the two dimensional valence arousal space.

The emotion extraction component based on EEG and physiological signals is analysed and described thoroughly below:

The emotion extraction service (BSPM) aims to develop Electroencephalographic (EEG) and physiological signal processing algorithms that will allow the recognition of users' emotional states in the two dimensional valence arousal space and drive the adaptation of the artistic installation.

This service will provide means to extract users' emotional states through the analysis and processing of physiological signals, e.g. electroencephalogram (EEG), Galvanic Skin Response (GSR) and Heart Rate (HR) measurements. Emotional state recognition from EEG and physiological signals usually consists of two phases: feature extraction and emotion classification. Key factor of an emotion classification model is the feature extraction phase. A variety of features have been proposed in the literature using time-, frequency-, time-frequency-based methods and non-linear approaches as well [17], [18], [19], [20]. The extracted features will be used in order to train several classifiers such as Support Vector Machines (SVM) [21], [18], [22], k-nearest neighbours (k-NN) [20], [23]. The technologies developed in this component will estimate emotional states while users will interact with a VR environment and corresponding art installations.

EEG and physiological signals will be acquired from lightweight recording devices. The portability and non-invasiveness of these devices foster their use in users' everyday life and promote the virtual experience.

Recently, the emerging field of Graph Signal Processing [24], [25], [26] (GSP) is applied on processing EEG and physiological signals. GSP combines traditional graph network theory with signal processing theory to analyse high dimensional signals. Graphs are generic data representation forms that are useful for describing the geometric structures of data domains in numerous applications. Recent studies have adopted GSP theory in their methods. The proposed study in [27] conducted graph analysis on EEG resting – state data in dyslexic readers.

In MindSpaces, our intention is to provide a novel emotional state extraction technique using GSP theory, validating its performance by comparing classification results from the proposed method and the conventional existing techniques.

The properties of the BSPM component are included in the following Table.

Table 16 BSPM Summary

Input(s)	Acquired bio signals from lightweight recording devices
Output(s)	Json format consisted of emotional state tags in the two dimensional valence arousal space, timestamps
Programming Languages/Tools	Python, Matlab
Integration	This service will communicate with BSDCS and a local storage service responsible for the pre-processing of signals, extraction of features and classification techniques, while it will also communicate with a data storage service for general storing of emotional state tags. It is an online service.
Dependencies	This service will use data from BSDCS.
Critical Factors	The processing time

Figure 16 shows some examples with different pairs of inputs and the produced outputs. Bio signals Processing Unit of Emotion Extraction service will receive EEG and physiological signals from BSDCS. Subsequently it will extract features of the collected signals and train emotion recognition algorithms with the extracted features in order to map them in the two dimensional valence arousal space.

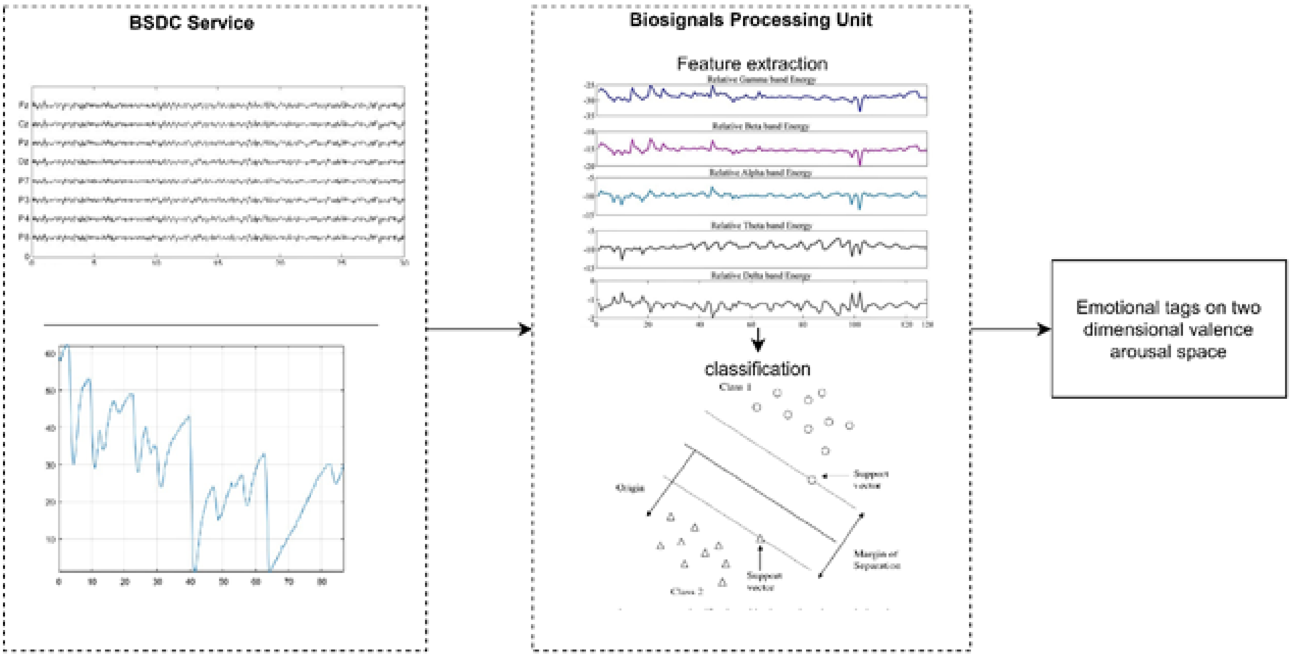

Figure 16. Overview of the BSPM architecture.

The logical design of the model is presented in Figure 17. Emotion extraction service will receive signals from Bio-Signal Data Collection Service's local storage. After receiving the signals, BSPM service will pre-process them in order to extract features and perform classification techniques to map these features in the two dimensional valence arousal space to extract emotional state tags.

Afterwards, it will upload the results on the FTP server and send a message on Message Bus that new results are available.

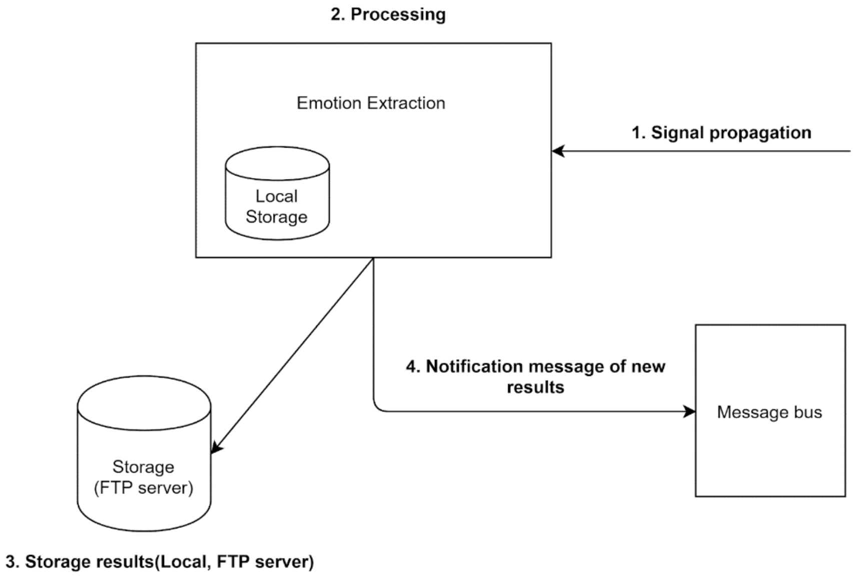

Figure 17. The Logical Design of the BSPM.

Development milestones: This service is currently under development, with expected delivery according to the following milestones:

- [M19]: 1st version (V1) of the basic techniques for real-time emotion recognition that rely on EEG and physiological signals. These basic techniques include algorithms developed for emotion recognition in the two dimensional valence – arousal space from EEG and physiological signals leading to some preliminary results testing their efficiency.
- [M34]: 2nd version (V2) of advanced techniques for real-time emotion recognition that rely on EEG and physiological signals. In the second version, emotion recognition algorithms, developed in 1st version, will be evolved to recognize emotional states in the two dimensional valence – arousal space. This improvement can include feature selection techniques or dimensionality reduction techniques, such as Principal Component Analysis (PCA) or Independent Component Analysis (ICA).

3.3.2 HUMAN BEHAVIOUR ANALYSIS FROM VISUAL SIGNALS

This module is a Human Behaviour Analysis (HBA) extraction service based on video signals. It is undertaken under the task T5.2. It involves one component with different inputs and outputs. This service uses computer vision, machine learning and deep learning for the representation of human behaviour in space and time.

The Human Behaviour Analysis component based on visual signals is analysed and described thoroughly below:

The HBA service aims to develop video processing algorithms that will allow the recognition of human behaviour of individuals and crowds of people, so as to support the adaptation of the artistic installation accordingly.

Video signals will be acquired from static cameras recording color video, as the non-invasiveness of these devices foster their use in users' everyday life and promote the virtual experience.

This service will provide means to extract users' behaviours through the analysis and processing of videos recording individuals and/or crowds, indoors or outdoors. A key factor of a human behaviour classification model is the feature extraction phase, often from pre-trained networks, which in the current SoA takes place via deep learning architectures [28], [29], [30], [31] will be investigated for action recognition and classification. Action detection may also be investigated, where relevant to the use cases [32], [33].

In MindSpaces, our intention is to provide a novel human behaviour analysis techniques using deep learning, validating its performance by comparing classification results from the proposed methods on benchmark datasets.

The properties of the human behaviour analysis component are included in the following Table.

Table 17 Human behaviour analysis component Summary

Input(s)	Acquired video signals
Output(s)	JSON format consisted of behaviour classification labels in space and time
Programming Languages/Tools	Python, Matlab
Integration	This service will communicate with cameras to acquire visual data, which will be analysed offline. The resulting spatiotemporal annotations of human activity/behaviour labels will be provided by this module.
Dependencies	This service will use data from video cameras
Critical Factors	The processing time

Figure 18 shows some examples with different pairs of inputs and the produced outputs. Video signals Processing Unit of Human Behaviour service will receive visual signals from cameras. Subsequently it will extract features of the collected signals and train human behaviour pattern recognition algorithms with the extracted features in order to characterize individual and group behaviours.

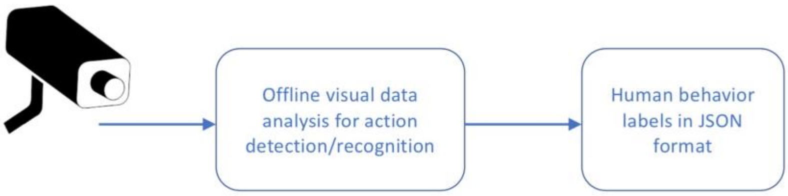

Figure 18. Overview of the HBA video analysis architecture

The logical design of the model is presented in Figure 3.

The HBA service will receive signals from video cameras and will analyse them offline to extract human behaviour labels. Afterwards, it will upload the results on the FTP server and send a message on Message Bus that new results are available.

Development milestones: This service is currently under development, with expected delivery according to the following milestones:

- [M19]: 1st version (V1) of the basic techniques for human activity recognition that relies on visual signals. These basic techniques include algorithms developed for visual behavior classification in space and time, leading to some preliminary results testing their efficiency.
- [M34]: 2nd version (V2) of advanced techniques for human activity recognition that relies on visual signals. In the second version, human activity recognition algorithms, developed in 1st version, will be evolved to recognize more complex human activities, leveraging the latest SoA in deep learning architectures.

3.3.3 KNOWLEDGE REPRESENTATION AND REASONING

This module is a semantic service that consists of the KB population component and the Semantic Integration and Reasoning component. It is undertaken under the tasks T5.3 and T5.4. It is responsible for the unification of incoming streams of data in RDF triples during the population of the knowledge base as well as inferencing new knowledge that might have remained hidden under different circumstances.

KB Population (KBP): The Knowledge Base (KB) population service concerns the service which maps various pieces of information incoming from multiple MindSpaces modules to the RDF-based representation format, that will depend on custom ontologies derived from existing ontologies and will be implemented during MindSpaces' scope. This procedure includes the implementation of vocabularies that will capture:

- The aesthetics and style which will be extracted from visual input (For instance, cultural heritage artefacts in paintings, images of artwork, video footage) and the textures produced so as to retrieve respective artwork attributes (aesthetics module in WP4)
- The semantic associations and dependencies (e.g. named entities, concepts, relations) extracted from textual analysis, as well as various metadata properties and contents of the social media and of the web data crawled within T3.4 (Linguistic analysis of archival material module in WP4)
- Exterior and interior objects and other content-specific attributes (e.g. textures, landscapes, art styles, etc.) that will be extracted from multimedia analysis modules (City Sensing module in WP3)
- Cognitive and emotional data extracted from EEG and physiological sensors from end users (Emotional and cognitive sensing module in WP3)

The knowledge structures will also supply for all the indispensable semantics required to generate textual descriptions for each component (Text generation module in WP5). The KB population service will support various mapping services, respectable to the format of the input of each asset, e.g. XML, JSON, etc. The service will be also responsible for updating the KB itself when incoming information is available from other components. The properties of the visual KBP module are included in the following Table.

Table 18 KBP Summary

INPUT(S)	analysis results from various modules
OUTPUT(S)	Updated KB (RDF triples that correspond to the incoming data)
PROGRAMMING LANGUAGES/TOOLS	Java, Tomcat, graphdb
INTEGRATION	The current service will communicate with other components via the message bus
DEPENDENCIES	Emotion Extraction module, Human Behavioral Analysis module, Aesthetics module, Textual Analysis module, Semantic integration and Reasoning module
CRITICAL FACTORS	The lack of specificity can lead to poor results with this component.

Below, a high level logical design of the KBP component is depicted, in which as the input data are incoming to the service, it creates RDF triples by mapping the information to the ontological model and saving it into the RDF Triple Store.

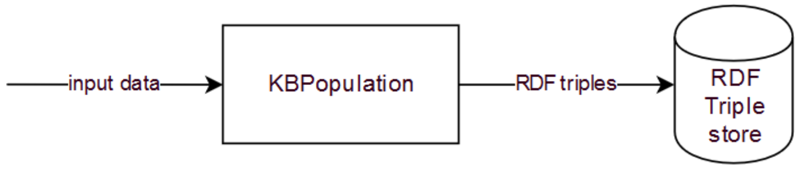

Figure 19. The logical design of the KBP component

Development milestones: The KB Population service is currently in a conceptual state and will be implemented and delivered according to the next milestones.

- [M07]: The foundational infrastructure of the service will be implemented, e.g. a dummy service (DS) capable of contacting bidirectionally the message bus, without any additional functionalities.
- [M12]: Fundamental mapping functionality (FMF) will be available as we move forward to v1. This includes the delivery of mapping algorithms responsible to populate the KB with real-case scenario results created by the current version of the MindSpaces modules. Additionally, the bidirectional communication with the message bus will be implemented and put to the test.
- [M20]: Fully working mapping service based on semantics and reasoning techniques, supporting the complete structure and content of the output created by the MindSpaces modules for V1. The algorithms adopted in M12 will be extended, taking into consideration possible updates and polishment occurred in the MindSpaces modules to address the user as well as the technical requirements.
- [M28]: Vital updates for V2, according to the updated structure and content provided by the analysis components. This includes further updates of the mapping algorithms to fulfil more advanced inputs derived from the components, likewise to update the publishing and subscription mechanisms to the message bus so as to realise the communication with the other modules of the framework. Additional work will be put forward towards the semantic enhancement of the incoming streams of information, for example, with the help of Linked Data principles.

- [M34]: Vital improvements on the final version (FV) of the system, relevant to the updates occurred on the output given by other components. Within the final version, the main goal will be the scalability and extensibility of the mapping algorithms, as well as on adapting strategies when the incoming information throws exceptions, such as incompleteness. Finally, the opportunity of a closer interplay with the Reasoning service will be researched as some kind of reasoning may occur within the mapping procedure.

Semantic Integration and Reasoning (SIR): The reasoning service will handle the further knowledge analysis depicted in the Knowledge base (KB). In more detail, the module will create a unified representation of the available resources, considering information relevant to texture and aesthetics (Aesthetics module in WP4), named entities, concepts and relations extracted from textual analysis (Linguistic analysis module in WP4), cognitive and emotional data extracted from EEG and physiological sensors (Emotional and cognitive sensing module in WP3), as well as exterior and interior objects and other content-specific attributes (City sensing module in WP3). At this point, the ontologies created by the KB population module will be the basis for the reasoning and information coupling algorithms (WP5), enabling the decision-making assets, respectively to the undefined use case requirements. Generally, the reasoning module will be responsible for acquiring higher-level knowledge that is not easily grasped by humans and will be generated by the output of other modules. The properties of the SIR module are included in the following Table.

Table 19 SIR Summary

INPUT(S)	RDF-based representations inside the KB
OUTPUT(S)	Inferences in RDF-based format.
PROGRAMMING LANGUAGES/TOOLS	Java
INTEGRATION	The Semantic Integration and Reasoning service will interact with the KB population service across the message bus.
DEPENDENCIES	KB Population
CRITICAL FACTORS	Extracting of irrelevant information could be distractive for the end user.

Below, the logical design of the SIR component is shown where the reasoning service is executed on top of the modeled data stored in the RDF Triple Store to extract further inferences.

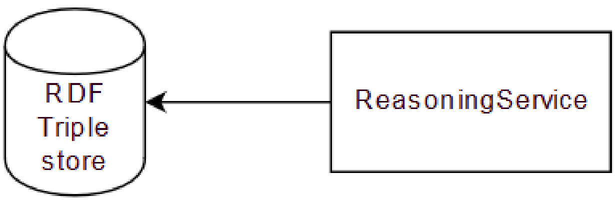

Figure 20. The logical design of the SIR component

Development milestones: The reasoning service is currently in a conceptual state and will be implemented and delivered according to the next milestones.

- [M07]: The foundational infrastructure of the service will be implemented, e.g. a dummy service (DS) capable of contacting bidirectionally the message bus, without any further functionalities.
- [M12]: The fundamental reasoning functionality (FRF) will be available as we move forward to V1, including the rule-based reasoning component capable of integrating resources and creating higher-level concepts, a fact that will finally enhance the context in a semantic manner.
- [M20]: The necessary reasoning functionality intended to fulfil the V1 requirements. More specifically, the basic semantics and reasoning techniques that will be applied so as to integrate all the information from the analysis so as to create novel 3D-models based on the end-user's emotions. This includes, real-time fusion which will be supported for emotion detection from multiple sources and intelligent aggregation and interpretation services which will be implemented to detect, from the available temporal sequences, emotion thresholds, patterns and variations that should be taken into account for adapting the 3D models. Forms of hybrid reasoning will be researched.
- [M28]: Vital updates for V2, regarding more advanced semantics and reasoning techniques that will be applied so as to integrate all the information from the analysis. Following a knowledge-driven approach, the service will be associated with pertinent emotion-driven adjustments and changes, taking into account the overall context of the interaction of the user with the system, based on domain and background knowledge.
- [M34]: Vital improvements for the final system will be regarded, such as scalability, whereas measures of similarity will be created for Linked Data resource linking and approximate reasoning.

3.3.4 TEXT GENERATION

Text Generation (TGS): The text generation service is undertaken under the task T5.5. It takes structured input from the knowledge base, which can originate from textual analysis of one or more input texts or from non-textual sources such as outputs from processing of EEG or visual signals (i.e., emotions and the visual behavior events/activities), and verbalizes the information as human-readable text in one of the supported languages. The graph-transduction grammars and lexical resources are used to perform the following steps:

- text planning identifies contents related to the queried entity, assesses their relevance relative to this entity, and produces an ordered sequence of linguistic predicate argument;
- linguistic generation starts by transferring the lexemes associated to the semantics structures to the desired target language;
- the structure of the sentence is determined;
- grammatical words are introduced;
- all morphological agreements between the words are resolved; the words are ordered and punctuation signs are introduced.

The aforementioned steps will provide a projection of complex ontological configurations onto lexicalized semantic structures and their subsequent realization as natural language sentences.

The properties of the TGS component are included in the following Table. The logical design of the model is presented in Figure 21.

Table 20 Text Generation Summary

INPUT(S)	linguistic and semantic structures from the knowledge base
OUTPUT(S)	generated plain text (in one of the supported languages)
PROGRAMMING LANGUAGES/TOOLS	Java
INTEGRATION	This service will exchange data with the database / knowledge base of the system. It will connect to the message bus for receiving new requests for text generation.
DEPENDENCIES	Semantic Integration and Reasoning, VR tool
CRITICAL FACTORS	The processing time: throughput varies based on number of input structures (e.g. triples). Typically ~3 seconds / document Scalability: can scale horizontally by adding computing nodes

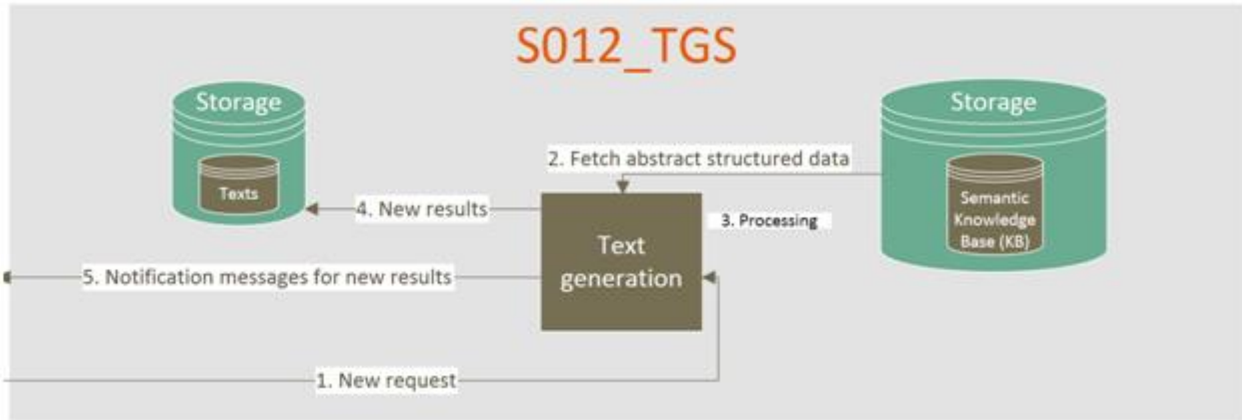

Figure 21. The Logical Design of the Text Generation Service

Development milestones: This component is currently in development, its expected milestones are the following:

- [M12]: Operational prototype (OP). Generation of a few sentences from ontological representations will be supported in English.
- [M19]: First version (V1) of text generation tools. The generator will allow producing multilingual texts from ontological representations so that the end-users could have an augmented textual information during their VR experience. Generation will be supported in two or three languages, and its coverage will be limited depending on the UC requirements.
- [M34]: Second version (V2) of text generation tools. The generator will handle all the languages of MindSpaces (English, Spanish, French, German, and Greek). For statistical generation, new linearization algorithms to cope with non-standard word orderings in different languages will be taken into account. The advanced version of the mapping of ontological representations to conceptual structures will be complemented with domain and application-specific methods, which will aim at optimizing the relevance and coherence of the descriptions. Efforts will be dedicated to ensure the reusability of the developed tools outside of MindSpaces.

3.3.5 Development of semantically enhanced interactive 3D spaces

In this task (T5.6), U2M will create innovative texture mappings in order to visualize on the surface of the acquired 3D models the data captured by the emotion sensors. In a way similar to heat maps, U2M will take data that corresponds to emotional levels and will compute novel texture atlases for the existing 3D mesh models. Using these atlases emotional maps will be draped onto the surface of the 3D models. Additionally, parametric models of spaces and decorative objects will also be created from the 3D mesh models via conversion of the geometries to NURBS so that their form can change with suitable selection of values for the descriptive parameters. The tuneable geometric parameters will be connected through a suitable designed control panel and linked to "listeners" that will get values in accordance to the users' emotional states. U2M in close collaboration with McNeel will deploy the right algorithms to parameterize 3D-models of indoors and outdoors spaces. MoBen, and AN will oversee the process as artists and potential users.

<u>Objectives</u>

- develop the algorithms to transform the 3D indoor and outdoor space according to the user responses
- visualize user responses (recorded via emotion sensors) on the 3D models
- change the form according to user emotional input

<u>Methodology</u>

- parametric 3D models of spaces and objects (probably mesh models to NURBS)
- innovative texture mapping via atlases
- emotional heat maps

<u>Expected results</u>

- transformation of textured 3D designs based on a user's emotional states

Table 21 presents a summary of space sensing for semantically enhanced interactive 3D spaces. The related technological objectives, activities and Key Results of the MindSpaces project are followed.

Table 21 Summary of space sensing for semantically enhanced interactive 3D spaces.

Input(s)	textured 3D models, parameters regarding 3d shape and texture
Output(s)	3D models
Programming Languages/Tools	Python, C#
Integration	The 3D models should interact with the user of the VR platform, so this module depends on the platform architecture.
Dependencies	**T3.1** Emotional and cognitive sensing; **T3.2** Visual sensing for behavioral analysis; **T4.1** 3D-reconstruction of urban and indoors spaces; **WP5** MindSpaces adaptive environment development; **T6.3** Development of adaptive AR/VR environments
Critical Factors	-

Research Activity

RA4.2. Adaptive 3D-models based on semantic reasoning

Key Results

KR10. Emotion-centric reasoning framework TRL 3 to 6 MindSpaces will develop innovative emotion-driven 3D adaptations, coupling at *real-time* different aspects of user needs, emotion characteristics and *3D model parameters*.

KR15. Efficient and user friendly virtual environments TRL 6-7 to 8 | In MindSpaces we are going to use VR/AR environments that are already have been implemented in various controlled environments and some are released in the market, leading to a commercial/industrial test outcome. **We will use parts of various previously defined environment to construct a product which is ready to go to the market as a separate module as well as a module of MindSpaces**.

KR14. Agile system architecture [TRL 3 to 7]: Currently there is no product combining all the services foreseen by MindSpaces. The integration of these services in a common platform and testing them in an operational environment in 3 realistic use cases is expected to bring the *technology readiness of the platform close to 6 or 7.*

Development milestones: The development of the data acquisition platform has not officially started yet. The T3.4 is starting, according to the overall schedule, at M7. It lasts till M34.

At this stage the development and implementation details of T5.6 are discussed in MindSpaces consortium. The relevant discussions are in accordance to the Pilot Use Cases requirements (WP7) and the integration aspects (WP6) and they are documented and constructed in the "T5.6 Development of semantically enhanced interactive 3D spaces - User and Tech requirements" document.

The corresponding internal deadlines are as follows:

- [M16]: Texture mapping (TM) of the user inputs
- [M16]: Mapping of the geometry (GM) of the user inputs
- [M18]: 3D meshes to parametric geometries (3D2PG)
- [M28]: End-to-end Module Prototype (P)
- [M34]: Corrections and performance improvement – Final Version (FV)

3.3.6 TIMELINE AND DEPENDENCY FROM OTHER MODULES

Table 22 WP5 Timeline

														D5.1, D5.3, D5.5															D5.2, D5.4, D5.6		
WP5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. Emotion Extraction Module based on EEG and Physiological signals															V1															V2		
2. Human Behaviour Analysis from Visual Signals															V1															V2		
3. Knowledge representation and reasoning																																
KB Population			DS					FMF								V1								V2						FV		
Semantic Integration and Reasoning			DS					FRF								V1								V2						FV		
4. Text Generation								OP							V1															V2		
5. Development of Semantically Enhanced Interactive 3D Spaces												TM, GM		3D2PG										P						FV		

3.4 MINDSPACES PLATFORM DEVELOPMENT & INTEGRATION (WP6)

3.4.1 3D TOOL DEVELOPMENT FOR ARCHITECTURE DESIGN

The development of the architecture design tool is undertaken under the task T6.2 of the Mindspaces project. At its core, it is conceived to facilitate the retrieval and visualization of assets generated by the Mindspaces platform, a set of loosely integrated and specialized services. In order to achieve this objective. The architecture design tool is conceived more as a toolkit than a single simple integrated application. The main component of this toolkit is a design environment compatible with 3D dynamic objects as well as geo-located dataset that can be overlayed in 3D space. This is called the Mindspaces Experimental Design tool, and it will be complemented with two other tools, one used for managing projects, assets, and services effectively, referred to as the "Project Management" tool; and another used to visualize and conduct analytical assessment of the data collected and generated. These three tools are explained in the following.

The Project Management tool: is designed to support the practitioner in defining and setting up a Mindspaces Project. It is the context in which the practitioner sets the configuration of the project and launches different analytical processes. Depending on the use case, the practitioner can execute the following tasks through the Project Management tool:

- Define and describe the Location of the project
- Define the themes or select the aspects of the project from a predefined set
- Import photos and videos taken in the location
- Import documents, surveys, and other notes
- And others

This tool will allow the practitioner to seed different processes in the Mindspace platform, which in turn will develop distinct data and knowledge sets that are subsequently used in the project, in the analysis as well as in the design and implementation.

In particular, the tool is intended to provide location and boundary information relevant to the virtualization of the project's location in order to empower the CAD-driven and data-driven design process. The virtualization is done by scanning and reconstructing the location within the specified boundaries in 3D. The tool also seeds the crawling and analysis of online information and data from specific sources to conduct an opinion mining over specific themes related to the practitioner's project. These seeds can be edited or expanded at any time to direct and redirect the opinion mining process, which include semantic analysis components capable of extracting meaningful patterns from the aggregated data. Opinion mining is a continuous process that may extend throughout the project, or until the practitioner turns it off. In addition, the tool allows the practitioner to import photos and videos taken in the project's location by the practitioner to capture specific features that could be aesthetically relevant to the project. This include architectural features of the location, iconic features, colors and texture, among others. These photos and videos are used by the Mindspaces platform to extract textures and aesthetic elements and facilitate their integration in the design solution that the practitioner is conceptualizing under this project.

In addition, the Project Management tool serves as a content management support for the practitioner, allowing creating different projects and managing the assets generated and imported under each one of them. The assets include, not only the seeds defined by the practitioner for each project, but also the information generated by the Mindspaces platform for this specific project (includes 3D models, datasets, and other digital assets).

The Analytics tool: is an elaborate dashboard developed to allow the practitioner to visualize and analyze the data acquired in the project. The Analytics tool is conceived to support the analysis of the following concerns for each project:

- Semantic analysis of the opinions mined by the practitioner in order to inform the project design.
- Data on human and machine flows in the designated location.
- Behavioral analysis of the people and participants in the location
- Geolocated emotional data acquired from EEG equipment.
- Open data sets related to the project location (namely applicable in open and public urban spaces).

The Analytics tool is designed to allow the practitioner to construct and examine the project from a data perspective, inspecting the collected data and analyzing the datasets to extract meaningful insights that will influence the design of solutions and artistic or architectural interventions. The Analytics tool will enable direct interaction between the practitioner and the collected data, allowing datasets to be crossed, compared, contrasted, summarized, and aggregated, among other analytical processes.

This tool will permit the practitioner to maintain a direct engagement with the data acquired in the project, and to make informed decisions when conceptualizing possible candidate solutions. This interaction is key to the success of the project from a data perspective. The practitioner can export the data and use it in other tools or as a primary material for the design, and in simulations such as VR applications. In addition, the data can also be used to empower dynamically evolving or changing solutions.

The Experimental Design tool: is a 3D environment built on top of Rhino3D engine and allows the practitioner to import and visualize assets related to the solution or intervention design. The Experimental Design tool is not a CAD design tool. The practitioner can use any of the available CAD design tools in the market to build designs in 3D with high fidelity and all the required details. The tool allows the practitioner to import these designed assets in an environment where the location of the project is virtualized and shown in 3D. In addition, several data layers are visualized over this environment to reveal behavioral and emotional patterns identified and analyzed in the Analytics tool.

In essence, this tool is an interactive integration environment essential for designing solutions and interventions in an experimental fashion, in which the data layers and the virtualized location provide the background for integrating design components. The final design can be exported and imported into compatible VR environments that allow the practitioner to perform walkthroughs, and experiments in VR with subjects of interest to capture more data related to their experience, including behavioral and emotional data. The acquired data can be re-analyzed and examined in the Analytics tool.

Status

The tools are currently in conceptual form, or corresponding to a Technology Readiness Level of 2.

Installation and deployment

The Architecture Design toolset would be installed via the Rhino Installer Engine, which is a separate executable installed along with Rhino 3D. This executable registers the .rhi extension on Windows and the .macrhi extension on macOS. The installation package is merely a compressed archive (.zip) with the contents of the compiled plugin and any resources needed to support the plugin. The .rhi or .macrhi package can be installed by double clicking on the file. This initiates the Rhino Installer Engine to evaluate the package. Once the package has passed the evaluation stage, the contents are copied in the appropriate locations on the user’s hard drive.

Technical requirements

The following summarizes the technical requirements of the user machine that will operate this toolset:

Operating System: Windows 10, 8.1, or 7 SP1 or macOS 10.13.x

CPU: Intel i5, i7, etc

RAM: 8 GB

Disk Space: 1.2 GB

Development milestones: According to the project development plan, the development of the architecture design toolset will take place according to the following scheme:

- [M12]: Early prototypes (P) of the Project Management and Experimental Design tools, early design of the Analytics tool
- [M17]: Early prototype (P) of the Analytics tool, consolidated prototypes of Project Management and Experimental Design tools (TRL-4)

- [M27]: First version (V1) of the three tools TRL-5
- [M34]: Final version (FV) of the three tools - TRL-7

3.4.2 VR TOOL

The VR Tool developed for MindSpaces platform will include 2 integrated tools, Firstly, a Unity Editor tool that will help in creating VR environments, and a VR Tool which can create adaptive VR environments inside Virtual Reality. The task of development is undertaken in T6.3. At its core, the tool will be developed on top of Unity3D Game Engine. Unity is the most widely used 3D development platform in the world[17]. It is one of the most widely used engine for Virtual Reality development. The Nuro VR tool will use the native functionalities of Unity but will add various new functionalities to use of MindSpaces repositories to extract assets and 3D models for the environments. Acting as a plug-in of Unity, a new tab will be added in the Unity which will be connected to the Backend tool.

Figure 22, shows a sample editor screen of Unity which has tabs of the Game, Scene, Hierarchy, Inspector, Project and Console. Similar to this, another tab will be include which will use the interface of the Backend Tool to show the repository of assets available for the users. The tool will be developed on C# and will use the APIs provided by Unity to integrate into the editor. Apart from this, the tool will provide new functionalities to the users to easily create VR environments, test them and produce gaming elements with pre-defined designs.

The tool will be developed by keeping the user requirements in mind and will use continuous integration/continuous development. The VR tool will be a toolkit comprising of both the softwares that can be installed on the users Unity installations. The VR Tool will be connected with the backend to send the information about the user's head position to have analytics on what they are watching based on the head tracking. This will be integrated with the EEG sensor data to get the analytics data regarding user's emotion.

[17] https://www.pcmag.com/feature/362057/how-unity-is-building-its-future-on-ar-vr-and-ai/2

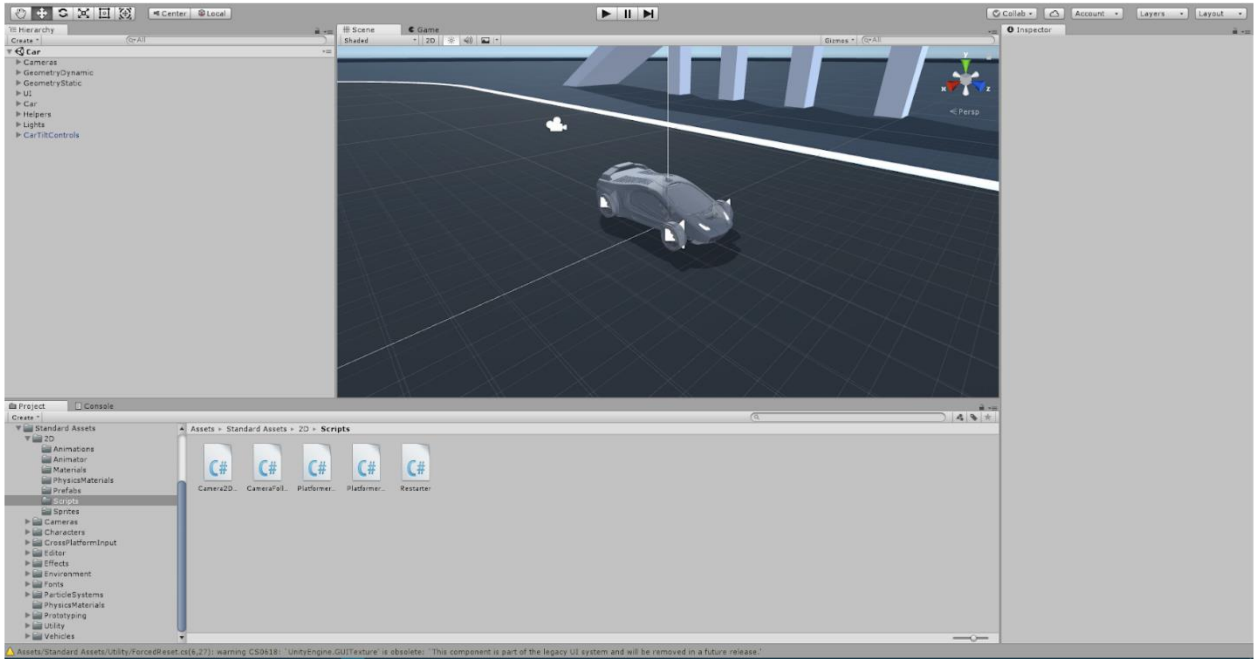

Figure 22. Unity3D Editor screenshot

The unity editor tool can be used to do the following:

- Import the 3D environments from the MindSpaces database
- Login into user accounts
- Import other relevant assets from the database
- Export the VR environment in a predefined setting.
- Import 3D environments with different aesthetics

The Virtual Reality editor tool will help in development of environments that can be modified in real time by edition of new 3D models and other assets. The user can also change the aesthetics and other features of the 3D environment

The VR editor tool can be used for the following:

- Realtime addition of 3D models into the VR environment
- Modification of size, rotation of the 3D models in the VR environment

- Deletion of 3D models from the VR environments
- Modification of aesthetics of 3D environments

Technical requirements

The following summarizes the technical requirements of the user machine that will operate this toolset:

Operating System: Windows 10

CPU: Intel i7, i9

RAM: 16 GB

Disk Space: 1.2 GB

Graphics Card: GTX 1060 6GB+

Development Milestones:

- [M12]: First prototype (P1): This will include basic functionalities considered as most important from the user requirements
- [M18]: Operational prototype (OP): First working prototype of the tool
- [M26]: First version of the tool (V1): The tool in TRL-5
- [M34]: Final version (FV): Incorporation of feedback and further changes. The tool in TRL-7

4 SYSTEM INTEGRATION (WP6)

As it can be concluded from the review of the defined technical components of Mindspaces in the previous sections, the integration task conceived for the project faces the prospect of connecting a heterogeneous set of modules, some oriented to user interaction, some to data processing, some to construction of digital objects, and some to the analytical modelling of different parameters.

In order to integrate the defined technical modules, a strategy has been devised in order to effectuate this process effectively and successfully. This strategy aims to reduce the risks associated with the integration of relatively large set of modules with different envisioned applications, developed by different entities, and in different frameworks. By doing so, the strategy ensures that the development of these modules can proceed in a near-ad-hoc manner, and that the preset milestones for the integration and delivery of different prototypes along the project are successfully met.

The type of architecture model appropriated for this setting has been chosen by taking into account the role of the technical Mindspaces platform in supporting the design, implementation, and evaluation process of artistic and architectural interventions in public, semi-public, and private environments. Accordingly, the architecture model, albeit preliminary at this stage, describes a set of loosely integrated and distributed machines: a user terminal that hosts the tools and the real-time processes that run in-situ; another cloud platform for remote services and other asynchronous processes. This is described in the following figure.

It is worth noting that both the user terminal and the cloud platform could be composed of more than one (physical and/or virtual) machine.

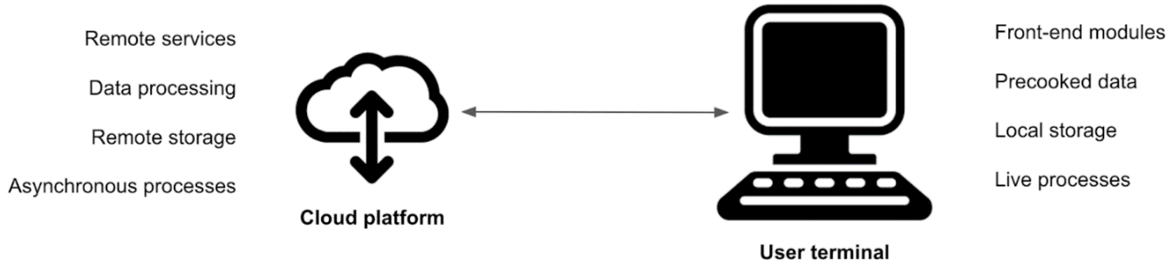

Figure 23. Separation of concerns in the architecture concept

The strategy adopted to integrate the technical modules into this architecture model rests on a triage method that allows to classify, separate, and address modules according to how and when they execute. For this purpose, the following classes have been defined:

- ***Configuration processes***: or processes responsible for generating an output that will be used as a background element in the project (e.g. the virtualization of the pilot use cases' locations).
- ***One-time processes***: or processes executed a single time upon the definition of a new project, or at any point in the project life from definition to implementation (e.g. modelling a dataset).
- ***Real-time processes***: or processes that execute continuously during a prolonged period of time in the project's life, for instance data simulations, VR, and other similar applications.
- ***Asynchronous processe***s: or processes that execute independently or asynchronously from the user interaction with the tool. Their output is delivered upon finalization of the execution in an ad-hoc manner.
- ***Chained processes***: or processes that each is composed of single elementary modules, the purpose of each module is to feed the following one in the process.

The integration strategy conceived calls for the following approach to integrating modules according to their classification:

- The modules of any configuration process are not considered as an integral part of the platform, but their output is incorporated by default in the integrated platform. This implies that configuration processes must execute outside the platform, but should mind the compatibility of their output with other platform modules.
- In order to maintain the simplicity of the integrated platform, efforts will be dedicated to explore if one-time processes can be transformed into configuration processes, thereby removing them from the platform. However, this is improbable in most cases since one-time processes are expected to rely on input from the project's own definition and parameters. We will aim to integrate light one-time processes on the user terminal, while heavy processes will be hosted on the cloud platform.
- Real-time processes will be integrated in the user terminal to insure smooth and effective execution, and exchange of data among tools and services. Hosting modules of real-time processes on the cloud-platform will be avoided.
- Asynchronous processes will be hosted on the cloud platform and called remotely from the user terminal. Due to the expected resource allocation for asynchronous processes, we might expect the cloud platform to contain at least two independent virtual servers.
- The modules of chained processes will be tightly integrated into single larger modules. These composite modules could integrate elements with different ownerships. Also, it is expected that each chained process would map closely to aspects addressed in a single work package. Therefore it is safe to assume that collaboration among partners responsible for building composite modules is already established under the corresponding work package umbrella.

In order to implement the strategy described above, we will follow the approach described in Figure 24. This five-step approach consists of defining each module clearly in a manner that informs its classification, then after the classification, proceed to design each machine where several modules are tightly integrated. Afterwards, the deployment model, including machine-to-machine communication protocol will be developed, and finally, based on the deployment model and the machine design, the architecture design will be formulated.

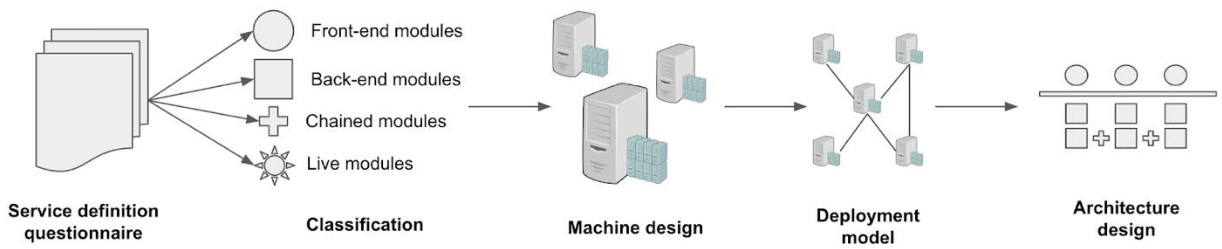

Figure 24. Strategy for integrating the Mindspaces platform

Under such an approach, we do not expect to iterate the design of the architecture, or in other words the architecture design is expected to stabilize early in the project, with no or little subsequent alterations.

Under the final design of the platform's architecture, a set of middleware components will be defined as an integral part of the platform, in order to insure communication and, where relevant, synchronization among the platform's components. For integrating the platform machines, HTTP protocols for sending requests and receiving responses between machines will be defined and followed. To insure interoperability, at least on the data management level, specific attention will be accorded to the definition and standardization of data structures to effectively govern data exchange. This would include the definition of application program interfaces (or APIs) that moderate machine-to-machine communication. In machines where components act as chained micro-services, the use of messaging and message queues will be assessed. Finally, considerations will be given to the storage and retrieval of data in centralized repositories, both on the level of the platform as well as on the level of individual machines. It is worth mentioning that the establishment of communications and data exchange between components, modules, and machines will be oriented to meeting the user requirements in terms of interaction, data search and retrieval, processing, and any other task defined in the project.

Development Milestones of the integration architecture design:

- [M7]: Completion of the service definition survey (SD)
- [M8]: Completion of the analysis and classification of the services (CS)
- [M9]: Definition of machines and deployment model (DM)
- [M11]: Final architecture design (FAD)

4.1.1 TIMELINE AND DEPENDENCY FROM OTHER MODULES

Table 23 WP6 Timeline

	D6.1							D6.2						D6.3								D6.4								D6.5		
WP6	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. 3D Tool Development for Architecture Design								P					P										V1							FV		
2. VR Tool								P1						OP									V1							FV		
3. System Integration - System Architecture			SD	CS	DM		FAD																									

5 DEVELOPMENT CYCLE AND PILOT USE CASES

The overall plan for the development of the MindSpaces platform is to start supporting basic scenarios and proceed stepwise by adding more features towards the final system. The detailed timelines of the individual modules, which are presented in previous sections will follow the general cycle: after the completion of each prototype version (timing defined by Milestones) of the MindSpaces (discussed in the next section), the functioning of the prototype is assessed, the needs for further development are identified and agreed upon, a detailed work plan for the next prototype version is finalised and the development cycle towards the next prototype is initiated. MindSpaces development plan includes the following prototypes:

- Operational Prototype: It is connected to the completion of the setup of the operational infrastructure of MindSpaces system;
- 1st Prototype: It includes the 1st version of the MindSpaces platform by integrating the basic techniques for the supported services/modules.
- 2nd Prototype: It includes the 2nd version of the MindSpaces platform
- Final System: The final versions of the MindSpaces modules with all functionalities fully available as planned.

MindSpaces solution will be evaluated in real world settings. Three Pilot Use Cases will be supported. The objectives of MindSpaces are presented in the following Figure.

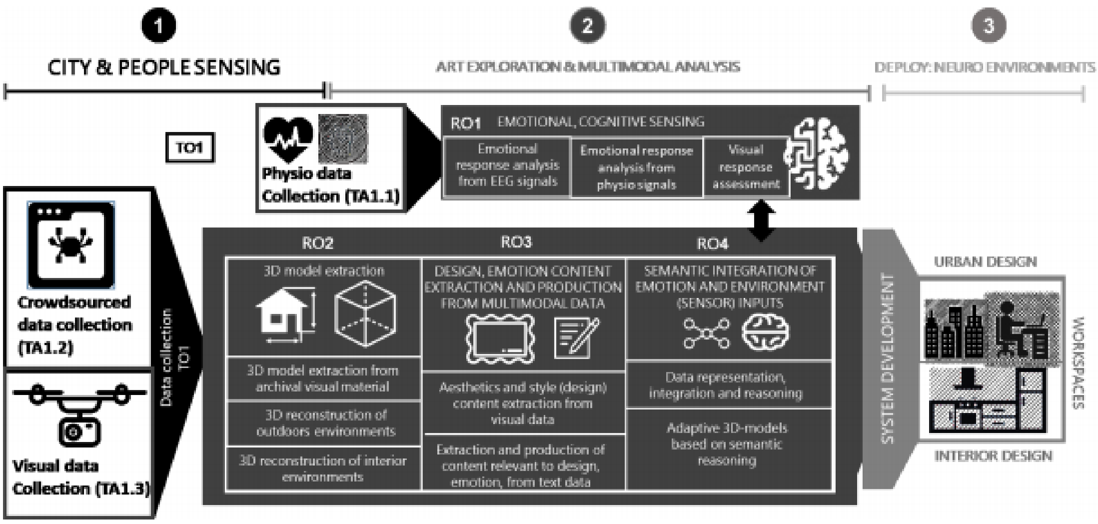

Figure 25. The objectives of MindSpaces

The supported Pilot Use Cases are described below:

- an outdoor installation that will be realized in Barcelona;
- an indoor workspace;
- an ambient assisted living facility for seniors;

5.1 Pilot Use Case 1: Outdoors urban environment

Motivation: In a rapidly expanding city, urban design is a challenging issue. MindSpaces aims to present the new challenges, raise visibility of the city's cultural value, and address the environmental and mobility issues. MindSpaces targets to increase the functionality of an urban area, and the sensitivity and awareness of issues related to its expansion. In this pilot use case an outdoor area will be examined. Innovative art installations in key locations will be proposed and created. New designs of the outdoor area under study will be provided to improve social interaction and new degrees of social connectivity with the urban fabric.

Story: A professional architecture office (Zaha Hadid Architects -ZHA) in collaboration with an academic unit and an artist's studio, have been assigned by a city mayor or council (City De Hospitalet) to produce a design proposal for an urban area of special cultural interest. They will use advanced modelling software (e.g. Rhino, Grasshopper) to produce blueprint documentation of the area, and propose new urban design schemes that showcase its cultural importance, generate new types of social interaction, and draw attention to issues it is facing.

The citizens will experience the proposed urban design in the outdoors area itself, through artistic interventions potentially expressed via physical art installations and/or new spatial installations linked with a VR environment. The art installations may provide direct representations of cultural assets, reproductions or projects on of the historical urban fabric, urban challenges, like mobility issues or environmental pollution data, aiming to elicit interest and engagement in these issues from city dweller and visitors.

User's emotional and cognitive responses will be indirectly assessed by a combination of environmental and physiological sensors appropriately chosen for each installation (EEG, motion sensors, activity sensors, video etc.). The MindSpaces public installations will dynamically change according to the artists' sense of aesthetics, in response to the sensor feedback from the public, so as to arrive at the most emotionally appealing and functional design proposal or/and a proposal which is generated through the collective behavior of the participants.

Testing environment: In this pilot use case, an art organization (ESP) is going to collaborate with an architecture office (ZHA), an architecture university department (AUTH) and independent artists (AN, MoBen) in order to renovate an outdoors urban environment, specified by a city council (City De Hospitalet). ZHA will generate the spatial interaction model to be experienced in VR in Unity 3d. Social interactions and actions between the user and the environment will be simulated and evaluated. The use case will be:

a. tested in [M20];
b. evaluated in [M28] and [M36];
c. Open demonstrations will present the outcomes of this PUC in the first open day [M31], to be held by ESP and NURO in Barcelona, Spain.

5.2 Pilot Use Case 2: Inspiring workplaces

Motivation: In recent years, aesthetically and functionally innovative workspaces are being designed and created to enable the dynamic communication that is needed within today's networked society. Increasing opportunities for positive social interaction in working environments leads to improved productivity and creativity across departments and teams. The general goals in PUC2 is to understand how people behave and feel emotionally in relation to workplace designs, create spaces which yield a more positive emotional state (lively and positive) and create designs with more/better social interaction and collaboration. Emotionally appealing working environments is a challenging topic for architects and artists. In MindSpaces, artists and architects will obtain direct user feedback as users are immersed in their designs and this output will be directly linked to generate more effective workplace designs.

Story: Current workplace design trends involve several design factors such as team interaction/collaboration, social interaction, green/light spaces, visibility/privacy, density and flexibility. Technological advances help artists and architects to integrate sensing tools and provide new ideas expressed by diverse technological means. In MindSpaces, 3D models of existing working environments will be created and serve as the basis for innovative design ideas. The latter will arise through the synergy of artists, creatives with architects, whose propositions will be presented in VR installations to end users. Online feedback from EEG, physiological sensing, integrated with environmental sensing, and Agent Based Parametric Semiology (ABPS) life process simulation modelling analysis will guide modifications to the initial designs to create environments that truly appeal to the people working in them and provide a platform for high quality social interactions.

Testing environment: In this pilot use case, an architecture office (ZHA) will collaborate with U2M, artists from the consortium (MoBen, AN) and artists invited from open calls to design friendly, emotionally sensitive and functional interior workspaces and interior objects. The use case will be:

a. tested in [M20];
b. evaluated in [M28] and [M36];
c. Open demonstrations will present the outcomes of this PUC in the second open day [M36].

5.3 PILOT USE CASE 3: EMOTIONALLY-SENSITIVE FUNCTIONAL INTERIOR DESIGN

Motivation Architectural and interior design involves the creation of emotionally appealing and functional environments. In recent years the integration of sensors in interior places provide the opportunity to assess and quantify the usability/functionality of a space and are widely used to support the design of better places.

Story: Seniors' home re-design: An association for elderly (eSeniors) in Paris, will ask a group of architects, such as a professional architecture office (ZHA) collaborating with an academic unit (AUTH) to make a proposal for the redesign and refurbishment of an existing home, with the goal of making it emotionally and functionally senior-friendly. Architects in collaboration with artists will design objects and spaces that evoke positive cognitive and emotional experiences and memories, by following design trends and aesthetic values likely to be appreciated by the elderly living there. 3D-models of the proposed designs will be imported in a VR environment so as to be evaluated from the end-users based on their EEG and other physiological measurements.

Testing environment: In this pilot use case, 3D-scanners from U2M will be used for the 2D and 3D-modelling of existing interior objects and spaces, forming the basis of new designs or reconstructions. Sensor based feedback of the users' responses (by EEGs, physiological sensing, visual tracking of activities, behavior and use of space) will be used by architects and artists to guide the architectural design and artistic exploration. Their initial design ideas will be imported in a VR environment (NURO) and will be assessed by the end-users via sensor feedback, leading to emotionally-adaptive design solutions. The pilot use case will be:

a. tested in [M20];
b. evaluated in [M28] and [M36];
c. Open demonstrations will present the outcomes in the first demonstration workshop in [M22].

6 PROJECT TIMELINE AND MILESTONES

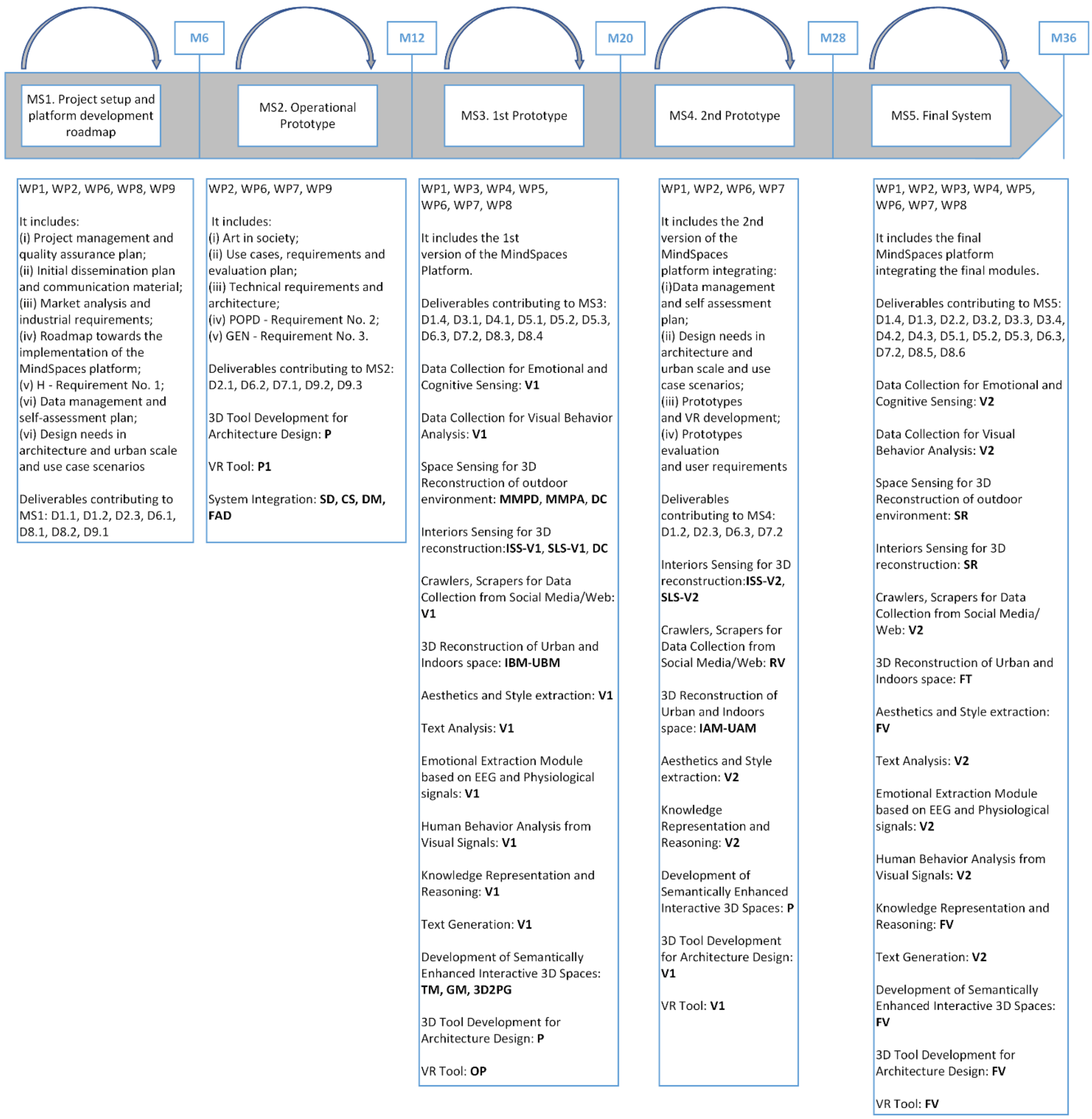

Figure 26. MindSpaces Project Milestones

MindSpaces platform will be built incrementally and iteratively. A project setup and platform development roadmap are included in the MS1. The MS2 includes an operational prototype. This milestone deals with the setup of the operational infrastructure of the MindSpaces system. The main idea during the development of the MindSpaces platform is to start with a "walking skeleton" [34] which is a tiny implementation of the system which performs end-to-end functions and links together the main architectural modules of the system. In the next phases of the development the functionality could evolve in parallel adding more functionalities and further capabilities on each MS. The completion of the first development cycle of the project is included in MS3. The first version of the MindSpaces platform will be delivered integrating the basic techniques. In the MS4 the second development cycle will be completed and the second version of MindSpaces platform will be integrated. MS5 marks the completion of the third development cycle which is the last development cycle. The final modules of the MindSpaces platform will be integrated. The following figure illustrates the timeline for the technical milestones in the evolution of the platform.

7 CONCLUSION

This deliverable presents the technical roadmap of MindSpaces platform. It includes the required information for the development of the project with a view to attaining the scientific and the technical objectives envisaged. However, since the project is following an iterative development procedure (use cases requirements-development-evaluation), it is expected that small adaptations and deviations on the initial technical specifications and the module functionalities foreseen by this document will be needed to satisfy the final user requirements. Potential changes/adaptations might be required at component or subcomponent level. The platform architecture together with the detailed specification of the modules (including any updates required) will be reported in D6.2 (Technical requirements and architecture).

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