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REMEMBER

EUROPEAN UNION

DELIVERABLE 3.1.3

Technical specification tender of the VM

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Index

Introduction

The present technical specification tender of the REMEMBER VM establishes a common set of information as basis for the PPs tender, enabling to reach the same digital outputs for all PPs or compliant with the project goals. The deliverable deals with details technology, structure, functionalities, costs, timing for realization, accessibility for disabled people.

The present deliverable gives requirements for obtaining the **Digital Experiences (DEs)**, reporting several kinds of **content (par. 1), equipment (par. 2)** and **technology development (par. 3)**. The DEs are connected to state of art technologies and able to serve both for tangible and for intangible heritage. The document is conceived as a catalogue from which the REMEMBER PPs should choose one or some solutions for the implementation of the local section of the eight VM. It provides also details in order to develop or subcontracting contents to be uploaded in the common cloud-based platform, that is introductory/common section (see the del. 3.1.1). **The information about the Cloud backoffice and Innovative functionalities, with first information about the "how to" upload contents in the REMEMBER platform, are in the deliverable 3.1.2.**

The present document is also inspired by the brief overview of the EU policy documents addressing digitisation of cultural heritage, in particular it takes in consideration good practices stemming from the Interreg Europe projects (Interreg Europe Policy Learning Platform on Environment and resource efficiency, 2018).

The Directive 2013/37/EU (amending Directive 2003/98/EC) lays down the general principle that documents from libraries, museums and archives shall be re-usable for commercial and non-commercial purposes. To facilitate re-use, public sector bodies should, where possible and appropriate, require documents with open and machine-readable formats and together with their metadata, at the best level of precision and granularity, in a format that ensures interoperability, and promote on line availability in open, machine-readable format together with metadata and the use of open standards. The contents provided by external experts in the REMEMBER project shall respect EU policies in order to allow their reusability.

According the Commission Recommendation on digitisation and online accessibility and digital preservation of cultural material, public institutions are invited to cooperate and involve the private sector in digitising their cultural material, in order to increase online accessibility of European cultural heritage and boost growth in Europe's creative industries. Currently, Europeana gives direct access to more than 19 million digitised objects. Only 2 % of these objects are sound or audiovisual material. Increasing the content accessible through Europeana, including types of material that are currently under represented, will make the site more interesting for the users, and should therefore be encouraged. (European Commission, 2011)

The concept of **interoperability** refers to the ability of diverse systems and organisations to work together. The term is often used in an information and communication technology (ICT) systems context (as per the definition above) but can also be used in the sense of broad social, political, and organisational factors that impact system to system performance. In developing these definitions further, a number of dimensions of interoperability have been identified:

Technical: technical interoperability, as noted above, refers to the linking of computers and services and enabling independent systems to exchange of information (e.g. interfaces, data integration, presentation, accessibility and security)

Semantic: semantic interoperability refers to the ability to exchange, understand and act on information and knowledge across different languages and organisational and individual cultures.

Organisational: organisational interoperability involves defining the necessary goals and processes to promote collaboration between organisations that wish to exchange information but have different internal structures and processes

Legal: legal interoperability is about developing the appropriate legal framework in different jurisdictions to enable secured access to and processing of information transferred electronically Interoperability is seen as both a prerequisite for and a facilitator of the efficient management and delivery of services, and is identified as a key factor in driving efficiency and the reduction of costs. (Centre for Research in Futures and Innovation University of Glamorgan, 2012)

Digital Experiences in VM

The use of information and communication technologies, as well as augmented / virtual reality devices, represents for museums and historical sites a process rich in opportunities, which opens a more effective and updated **dialogue** with existing and potential **audiences**.

However, the design of digital technologies requires a **strategic vision** that allows to place the technological element in a coherent plan of communication of identities, memories and cultural contents, starting from a clear identification of the objectives and aims of the interventions.

Implementation of digital technologies, where well addressed and employed, can generate great opportunities to **organize and enhance public memories** towards local community, new generations and tourists, and to **provide contemporary meanings and renewed vitality** to the maritime cultural heritage, both material and immaterial, of the Central Adriatic area.

The realization of VM and digital applications can represent an intervention of **audience development and engagement** but it's necessary that these digital experiences answer both to **educational and didactic requests** and to the need for **emotional involvement** of the end-users.

Indeed, digital language can be applied with a primary educational purpose, conveying contents that would otherwise be difficult to communicate (e.g. virtual or augmented reality reconstructions of works and pieces; diagnostic data on assets or monuments; ...). Moreover, digital technologies also allow us to act at an informational level in a more effective and immediate way, communicating to tourists and occasional visitors the main contents and key concepts relating to the history and identity of a territory or a specific site (e.g. sensible spaces; tourist apps; ...). Finally, the use of digital technologies plays an essential role in the creation of highly evocative and engaging products and installations, which allow visitors to learn about cultural heritage and sites through more stimulating, emotional and interactive experiences (e.g. augmented reality 1:1 in archaeological sites; immersive virtual reality; spatial AR; ...).

These different approaches, which may also intersect or overlap, have to enhance the cultural asset/site in a **user-centred perspective**. Therefore, it is necessary to identify the target groups to which the digital experiences are addressed, in order to define the right languages and the appropriate type of interaction. This operation must be carried out both towards an already existing public, of which habits and methods of use are known, and towards the new audience, which could be attracted through the use of these technologies.

It's necessary to conceive digital content as part of a single narrative of the cultural asset/site. In this regard, a **cooperation of technological tools and languages** is needed to harmonize and homogenize each DE with the cloud-based platform.

In order to do this, it is essential to include within the working team one or more figures with competences in the communication of cultural contents through new media. In particular, the **project manager/designer** has in charge the **architecture of digital contents and related technological applications**. He has to coordinate the various actors involved in the digital experiences, in order to identify a common line in terms of **editorial line** of texts, images and audio-visual contents and a common **visual identity.** He also ensures an overview of the ways of **interaction** between users and digital tools.

According to best practices in VM implementation, the present Deliverable builds up a DE as a sum of three distinct items (see following scheme). Consequently, the implementation costs for these digital experiences of cultural heritage enhancement will be composed of:

- **content**, which include costs related to the production and post-production of texts, images, photos, audio-visual contents, 3D models, diagnostic data, as well as costs for translations into other languages;
- **equipment**, which includes the costs related to the purchase of hardware and software components;
- **technology development**, which includes the development costs of the contents produced and the adaptation to the different devices, according to the type of desired experience.

Costs relating to the design, testing and maintenance of the digital experiences are usually calculated as a percentage of total costs.

For the **design activity**, the range can vary from 10% of the total, if it relates only to the design of the content architecture and the digital strategy, to a maximum of 20% if it includes the **management activity** in the execution phase of the works.

The **cost of testing** can range from 2% of the total, if it is a simple test of regular execution, to a maximum of 7%, if it includes usability tests with samples of users, to be conducted both in ongoing and ex-post phase. Analyses of the **usability** of digital experiences are of great importance to evaluate the **effectiveness** of the interaction between users and applications, to monitor the degree of user **satisfaction** and to implement timely interventions to improve the service (see V-MUST DEL 3.2, 5.4).

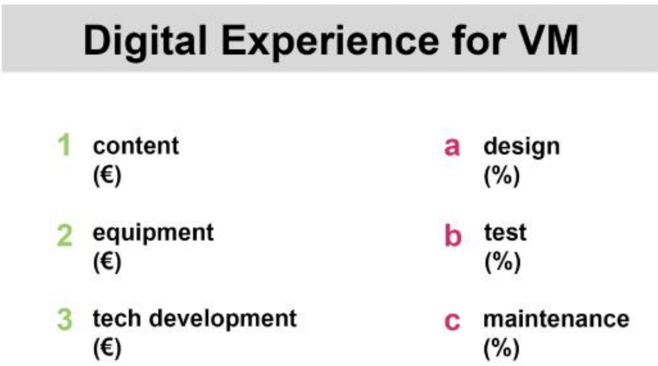
Operating and maintenance costs, which may concern the renewal of software licences, subscriptions for digital distribution, updating of digital content, etc., may be in the range of 3 to 5 % per annum.

In addition to these costs, other items, not strictly belonging to the investment for the technological realization, are:

- the creativity aspects, linked to the whole design experience and/or to creation of texts, storyboards, images and audio-visual contents;
- the preliminary work of research and the scientific consultations and curatorship;
- general fitting-out works (building works, carpentry, plant engineering, ...)
- surveillance, training and updating of museum staff, where needed.

The DEs for implementation of VM can be subcontracting as a whole, according the following formula. In this case, all the expenditures shall be considered in the budget line **external expertise and service**. Otherwise, **the equipment** could be separately purchased, rented or leased.

Digital Experience [€] = content [€] + equipment [€] + technology development [€] + design and management [%] + test [%] + maintenance [%]



The suggested ranges of costs refer to **highly variable market conditions over time**. It should be also considered their volatility depending on the multiplicity of technological solutions and the possible configurations for each following DEs. Because the author of the present deliverable is not a provider or producer of hardware, **the costs here contained purely serve for a preliminary estimation**. All PPs are required to contact specialized companies and are subject to full respect of EU, national and Programme procurement rules. PP9 UNIVPM does not accept responsibility for possible variations and differences between the costs here indicated and the market condition in the moment of the request.

Focus on accessibility for disabled people

One of the tasks of project manager/designer is also to supervise the **accessibility** of digital experiences to audiences who differ in perceptual, physical and cognitive abilities. In fact, it is important to design experiences of fruition and enhancement of cultural heritage able to expand the public, responding to the needs of a plurality of categories of visitors. **In addition it should be highlighted that accessibility for disabled people is stated in the Application Form and it become in this way mandatory, according the concept in the Del 3.1.1 (see paragraph Target Groups and Engagment).**

Immersive and entirely digital experiences are generally precluded to the public with **sensory disabilities**. It is therefore necessary to implement alternative communication strategies, capable of conveying in an equally effective way the contents of digital experiences.

However, there are some general guidelines that are useful to ensure that digital contents, whether accessed online or on site, are **inclusive and accessible**. Digital experiences should:

- can be used by anyone in a fair and completely autonomous way,
- adapt to the different abilities of the users;
- allow intuitive use;
- stimulate as many senses as possible, providing information through different channels;
- minimize the risk of unintentional errors;
- minimize the physical effort of the visitor in the interaction/use.

A **website or mobile application** is accessible when it provides information that can be used by all users, including those with disabilities.

A website accessible to all complies with European directives.

Accessibility ensures that users with different types of needs or functional limitations can use the Internet **without restriction and independently.**

The following are the areas on which attention should be paid to making a website accessible:

- **Perception**. Depending on the type and degree of disability, some users may not perceive, in whole or in part, all the elements included in the site. Blind people, for example, navigate without being able to rely on visual stimuli.

Nevertheless, there is a tool called “screen reader” that reads the contents of the website and transmits the readable data to the assistive technology (display for Braille, speech synthesis tool ...). Some stimuli, such as background music, can become disturbing elements.

-**Understanding**. Do not use acronyms and abbreviations that may be difficult to understand.

-**Interaction and navigation**. It strongly depends on the structure of the site, which should be as clear and intuitive as possible. Each website should be designed so that it can be navigated using supporting technologies (e.g. instruments that capture eye movements, keyboard navigation...).

A few simple instructions should be taken into account when designing and building a site. In general, the same graphic instructions provided for texts (enlarged characters, text in contrast to the background, etc.) apply to both sites and apps.

We also recommend:

- **give each image an alternative text** describing its content;
- **make navigation easy**, possibly with a single menu;
- **allow to customize the size of the characters and the contrast** between text and background;
- **use a simple language**;
- **subtitle** the video contents;
- **add audio descriptions** where necessary.

In particular the contents have to be uploaded according to W3C Web Accessibility Initiative (WAI) guidelines[1].

[1] https://www.w3.org/WAI/

Technical specifications

1. Contents

The cloud-based platform of REMEMBER VM should use a **common language**, where all PPs undertake to custom the same technical specifications regarding the contents: texts, images, audio-visual contents, 3D models, diagnostic data.

1.1. Texts

Description:
The drafting of texts and information content should involve experts such as researchers, copywriters and translators.
In the elaboration of the texts it is necessary to consider: **different needs** related to the different target audiences; **level of detail** necessary to communicate the desired contents according to the aims pursued; **different ways of fruition** of the texts.
In any case, there are some **general guidelines** to follow so that educational and informative texts are easy to read and understand:

- **elaborate short texts** (about 45 characters per line) and **divide them into paragraphs** (4-5 lines each);
- give **information in a logical order**, distinguishing between the basic and derived information;
- **express one main concept per sentence**;
- **use a simple, non-specialist language**, defining the technical terms (when it is necessary to use them);
- avoid the overload of information and **point out concepts**;
- **avoid the academic, formal and impersonal style** of writing, preferring a conversational style;
- preferably **use the active form of verbs** and express the subject at the beginning of the sentence;
- **avoid subordinate sentences**, syntactically complex constructions, unnecessary adverbs;
- use underlining and **highlight key words** with bold.

Regarding the architecture of information, it is important to remember that each text must have **different levels of detail** and **different codes of expression** depending on the type of audience and the aims pursued.

In particular, for didactic and educational purposes, it is useful to present the contents in a hierarchical form, in which the fundamental notions can be communicated through a first level that is more comprehensible and immediate, while further additional information and collateral issues can be included in subsequent levels of discussion.

If the target audience is foreign tourists, **translations** of all the texts should always be provided.

For the **public with sensory disabilities**, methods of **autonomous use** of the contents should be preferred.

For **blind people**, knowledge of things involves intact perception channels: touch and hearing. Therefore, **all written texts** must be transposed into **Braille** (if part of a physical set up) and/or proposed in an **audio version**.

For the **visually impaired**, all the instructions given for the blind are valid.

It is also important not to forget aspects that may facilitate readability:

- **use sans-serif fonts** (arial, elvetica bold, sans serif or verdana);
- **use a double or triple line spacing** and adequate spacing;
- **place the text on a single column**;
- **align the text only on the left** (no justification);
- **allow the characters to be zoomed in**;
- **the background must be uniform and contrasting** (dark text on a light background, or vice versa).

In the case of **texts in physical settings** (panels, labels, plates, etc.), the following aspects must also be taken into consideration:

- **use characters with a width of not less than 2,5 mm and a height of not less than 4,0 mm** (arial:16 points);
- **avoid transparency effects and reflective surfaces**;
- **avoid the projection of shadows** on surfaces;
- **prefer homogeneous lighting** that is not too low or excessive.

<u>Cost:</u>

The costs proposed here, relating to the editing of texts, **cannot take into account the scientific research activity**, which must always be considered in order to develop authoritative and reliable content. The average cost of a copywriter who produces text content is about 40.00 euros per folder.

The costs of foreign language translations, which must always be provided by specialized translation agencies, are about 20.00 euros per folder.

The realization of Braille translations should be committed to companies specialized in the field, which can also take care of the choice of media and the proper positioning of the same. The costs of Braille obviously vary according to the type of medium on which the print is to be made; on paper the approximate cost is €35.00 per folder.

1.2. Images and spherical photos

Description:

Before producing new photographic acquisitions, search free-to-use images online into open digital library. When it is necessary realised new digital objects, it is very recommendable share them among the PPs of Remember project and make them available online with free licenses, in order to increase online accessibility of European cultural heritage, as Europeana suggestions.

For instance, CC Search[2] is a tool that allows openly licensed and public domain works to be discovered and used by everyone. Creative Commons, the non-profit behind CC Search, is the maker of the CC licenses, used over 1.4 billion times to help creators share knowledge and creativity online. CC Search searches across more than 300 million images from open APIs and the Common Crawl dataset. It goes beyond simple search to aggregate results across multiple public repositories into a single catalogue and facilitates reuse through features like machine-generated tags and one-click attribution.

Minimum requirements:

Images must be at least in HD resolution (1920 x 1080 pixels) or higher, better if 4K (3840 x 2160 pixels). For print the images, it is necessary a resolution of 300 dpi and the size equal to the real size of the print.

[2] https://search.creativecommons.org/

The file type can be .tiff (without compression),.jpg (with compression), or other format that keep the images quality.

HD Mosaic Images (scale 1:1) are usually used for digitalized the pictorial art. The reproduction of colors have to absolutely faithful. The zoom in to enlarge can interested any area or detail without losing image quality. In this case, the pixel size depending on the real size of object. The visualization of this type of images usually occurs through a pyramidal structure that increases the detail/size with the increase the zoom. For realize these images, the photographic equipment is similar to professional macro photography. Cameras and lenses must be of excellent quality. The acquisition distance and the diaphragm opening must be calibrated so as to obtain the right depth of field to have whole object in focus.

Spherical photo is an image created starting from pictures of a certain scene, e.g. a landscape or a site of interest, taken from the same point in different directions, which condensate all the visual information of these views. This panoramic image can be easily navigated, changing freely the viewpoint.[3]
It must be 360º and not have breaks in the images on the horizon. These images should not extend to the zenith and nadir (from top to bottom); however, only slight interruptions are acceptable between the upper and lower edges of the spherical photo. Minor joining errors are allowed, while spherical photos showing very obvious joining signs may not be accepted. Generally, for good visualisation, spherical photos must have the minimum resolution of 4096 x 2048 and the maximum resolution of 16384 x 8192; the value below the threshold have not the sufficient sharpness, above the threshold, it isn't performant online and it would take too much time for loading. The aspect ratio is always 2:1 in the equirectangular projection and 1:1 for every one of six images in cubic projection.

Cost:
The cost of the images is too variable: it can be a photographic shot without post-production, a graphic illustration of a famous artist, an infographic or other.
For a single shot, a professional photographer could ask from € 50 to € 250.
The cost of HD Mosaic Images depends on the size of real object and its accessibility. Acquisition alone costs from 100 to 300 euros per hour, with standard instruments.
For the spherical photos, is usually to pay:

[3] V-MUST project, Deliverable 4.1. http://www.v-must.net/media_pubs/documents

20-40 €/photos by 360 automatic camera;
40-60 €/photos by HD Reflex Camera.

1.3. Sounds and videos

Description:

Audio-visual content can be proposed to create multimedia experiences in order to involve visitors in the narration of places. Particular attention needs the production of contents for audio and video guides and for audio-visuals.

Audio guides are useful where it is necessary to accompany the visitor along a path, to provide information and / or insights.

There are some general guidelines to ensure that informative contents are easy to listen to and understand:
- elaborate a persuasive communication strategy through **storytelling** techniques;
- propose **short audio** (maximum 3 min.);
- **give information in a logical order**, distinguishing the fundamental from the derived ones;
- **express one main concept per sentence**;
- **use a simple, non-specialist language**, defining the technical terms;
- **avoid information overload**;
- **prefer a direct, non-formal style**;
- **avoid subordinate sentences**, **syntactically complex constructions**, **unnecessary adverbs**.

It is essential to take into account the **fruition time** of visitors and the **different needs of the public**.
It would be appropriate in fact:
- to create an **audio guide suitable for children** that follows the same path as the adult version;
- to provide **content in several languages**;
- to create **descriptive audio guides for the blind**.

Audio guides for the blind, like audio descriptions, must offer the same content as that offered to other audiences. In addition, descriptive information on visual aspects should be included. If the audio accompanies a video, all the events in which speech is missing must also be told.
Good practice to verify the effectiveness and validity of audio guides would be to carry out **usability tests** on sample users, which correspond to the targets you want to reach.

Video guide

For **deaf people**, the most immediate and effective perceptual channel is the visual one.

The best way for hearing impaired people to access the content is to create a **video guide,** a sign language film. Good practice would also be to insert **subtitles** and an **audio track**, so that the video meets the needs of the widest possible audience. The subtitles, written in white on a dark background, can also be proposed in two languages. The video guide can be viewed through technological devices such as tablets, smartphones, computers or totems. Good practice is to insert images for comparison and that contextualize what you are talking about.

The single video tracks can have a variable duration depending on the type of content they have to communicate. In general, it is recommended **not to exceed 5-7 minutes** each.

Written texts are not equally effective but can be used, as long as they comply with the good rules for effective communication.

Audiovisual

The moving images accompanied by audio are familiar to every segment of the public because they are the basis of the media used daily. These attract more attention from visitors, allowing more effective transmission of information. The **audiovisual medium** can perform both the informative function of the panels and can be documentary evidence, such as a historical film, or be a medium for reconstructions and animations.

The **sound element** plays a decisive role in the involvement of the visitor and in the construction of emotion because it helps to broaden the sensory perception compared to the visual one.

Measures for an optimal production and enjoyment of audiovisual works:

- **use quality images and audio**;
- **propose attractive graphics**, in line with the physical layout or the graphic aspect of the site/app;
- **vary the rhythm of the narration** to keep the visitor's attention alive;
- **take into consideration ways and times of fruition**. When using the site remotely and via smartphone, it is advisable not to exceed 5 minutes. In the case of an experiential and/or immersive installation on site, it is advisable not to exceed 10-12 minutes;
- in the case of an on-site installation, **take into consideration the lighting conditions**, also depending on the instrument used;

- in the case of a physical installation, **avoid interference between sounds** by selecting the most suitable diffusion/use instruments for the context;
- in the case of a physical installation, arrange furnishings and objects in such a way as to optimise use.

Creative works (musical, literary, theatrical, cinematographic, lyrical and visual arts) are the expression of an intellectual work that the law protects with **copyright** and **related rights**. It is essential to take into account the need to request any rights for the reproduction, and possible reworking, of audio and images. It is possible to use **open source** content.

Minimum requirements:

N/A

Cost:

The term "audiovisual" refers to a wide variety of cases, which involve the use of different skills, abilities, knowledge, equipment and resources. The only way to correctly estimate costs, times and methods of execution is to request a detailed quote. Here it is only possible to estimate a range of €1000.00/min - €3000.00/min on the basis of the professional figures involved, production costs (locations, sets, technical means...) and post-production costs.
Audiovideoguide cost in sign language with subtitles: €500.00/min.
Audioguide cost: €100.00/min.
Soundings cost: €200.00/min.
The costs of foreign language translations, which must always be carried out by specialized translation agencies, are about 20.00 euros per folder.

1.4. 3D models

Description:

Modeling methods can be classified according to the perception modalities of the intended user and aspects of the simulated objects in the VR environment. Accordingly, from a sensory perspective, modelling methods are classified into visual, auditory, and haptic. From the simulated object perspective, on the other hand, the modelling methods are categorised into scene appearance, physics-based behaviour, and real-virtual combined modelling. During actual modelling, there are three guiding factors for determining which model data type and modelling method to employ—complexity of objects in the real world, the users' intended modality, and the expected degree of model fidelity.

Often multiple modelling methods and model data acquisition techniques are combined to generate model data to satisfy the required model fidelity.

3D models are widely used in Virtual Museums, to show a collection of objects, to build a virtual reconstruction, to plan a virtual restoration, for documentation purposes, and so on. 3D models can be built from scratch manually with a geometric modeling software by an artist/designer or acquired automatically through laser scanning techniques or image-based modeling. Computer Vision techniques can also be employed to generate the model automatically starting from a set of images. In museums, the 3D objects or the whole environment are displayed for several AR / VR applications.

Minimum requirements:

For a smooth navigation the 3D models must be the compromise between resolution and file size. Both reality-based models and computer graphics models, whatever the modeling process, must not contain many surfaces. A good 3D model for visualization is LOW Poly with an applied texture having the right resolution to perceive details. A good 3D model can be considered as such if it allows a good perception of both the shape and the surface texture. The 3D models can be used to render in 2D prints, videos with animations or physical objects printed in 3D. According to the finality there are precautions to follow for the correct modeling. For example, not all models can be printed. In 3D printing meshes are used, these are geometries for which the shape of a polyhedral object is defined by vertices, edges and faces. These faces are generally triangles. The modeling program creates this mesh by exporting a file of .STL or .OBJ format, which is then imported into the slicing software. 3D modeling software generally has plugins or features useful for checking and correcting exported meshes. When a mesh has problems, the slicer can incur serious errors in interpretation, causing the printing process to fail.

Cost:

To evaluate the cost of a 3D model, it is necessary to understand which modeling process must be addressed, what is the complexity of the building, the level of photorealism and the quality of rendering. A reconstruction from historical sources will require a study calculated separately. A reality-based model may require the use of very expensive equipment.

For these reasons, the cost can range from € 1000 to € 10,000 for 3D models of objects and go up a lot for reconstructions of architectural environments or urban scenarios.

1.5. Diagnostic data

Description:

Diagnostic survey is an important contribution for describing the preservation state of the artefacts and cultural heritages as well as for investigating the condition of historical buildings. Diagnosis is based on qualitative and quantitative approaches. The first one is determined by direct observation of the structural damage and material decay as well as historical and archaeological research; the second one is mainly characterized by material survey, monitoring and structural analysis, involving in-situ and laboratory tests. From different diagnostic methods, Non-Destructive Testing (NDT) has become very popular for its non-contact, quick and accurate defect detection, involving different results related to the different theoretical principles adopted and the different physical properties of the investigated structure. Amongst these NDT techniques, today Infrared Thermography (IRT) is widely employed for the restoration of cultural heritage, ranging from the assessment of properties of building materials and structures in civil engineering and construction, to the investigation of the state of conservation of the historical sites or archaeological remains. One of the main advantages to adopt this technique is the possibility to investigate either large or small areas without any contact and invasive analysis.

Minimum requirements:

1.5.1. Infrared Thermography for diagnostic survey

The standard procedure for thermographic inspection is defined in the UNI ENI ISO 9712:2012[4] guidance and must be conducted by a certified thermographic operator. The measuring principle is based on the physical phenomenon of energy radiated by the surface of an object whose temperature is above absolute zero (-273.15 °C).

There are four operating bandwidths available for infrared systems:

- from 0.8 µm to 1.7 µm (near-IR or NIR Near-Wavelength IR)

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[4] UNI ENI ISO 9712:2012. Prove non distruttive - Qualificazione e certificazione del personale addetto alle prove non distruttive, 2012

– from 1 to 2.5 μm (short-IR or SWIR Short Wavelength IR);
– from 2.5 to 5.5 μm (mid-IR or Mid-Wavelength IR);
– from 7–8 to 13–14 μm (far-IR or LWIR Long Wavelength IR).

In general, the focus of the IR monitoring is the temperature difference, in order to quantify the anomalies by the Thermal Index (TI) as following:

$$T = \frac{(T_S - T_O)}{(T_A - T_O)} \tag{1}$$

Where:

T_S = Temperature of the anomaly (°C) measured by the infrared camera on the area affected by the defect;
T_O = External temperature (°C);
T_A = Internal "ambient temperature" (°C).

IRT inspection can be distinguished in two different approaches:

(1) Passive thermography used when the features of interest are naturally at a different temperature than the background. It is commonly used for the qualitative inspection of architectural surfaces (detection of discontinuities/interfaces, defects, voids, etc.).

(2) Active thermography, which employs an external source to produce a thermal contrast (heating or cooling) between the feature of interest and the background. In this case, it is also possible to obtain quantitative results. The methods adopted to generate the necessary heat into the structures provide a further classification in thermography (Usamentiaga, et al., 2014):

- Conventional thermography or step heating: the investigated structure is subjected to a continuous heating/cooling (long pulse) and the temperature evolution is analysed.
- Pulsed thermography: short thermal pulses by powerful flashes are applied. The material discontinuities are identified by the reduced diffusion rate of the thermal front with respect to the surrounding areas.
- Lock-in or modulated thermography: thermal waves by cyclic modulated heating (generally with halogen lamps or heat guns) are generated inside the investigated structure and the temperature of each point on the surface over time is acquired. In this case, it is necessary to synchronize heating and acquisition. This method is more sensitive but very slow, because for each depth different excitation frequency and several cycles are required.
- Laser excited thermography: the heating process is localised to a spot or a line on the surface and the intralaminar (perpendicular to the surface) defects, not detectable with traditional flash lamps, are identified.

- Ultrasound thermography: ultrasound waves are propagated through the material and the local thermal gradients, depending on the variation of the frequency indicate the presence of the defect.

The natural environmental heating/cooling variant is preferred, by using the sun during the day and fresh air during night, which is enough to generate measurable differences. The active variant of thermography is suitable for detection of defects (voids) inside materials of low conductivity, e.g. plaster detachment or hidden structure of masonries.

1.5.2. Infrared camera sensor

The thermographic sensor, namely infrared camera, provides the heat emitted by the objects surface without any contact, detecting any irregularities of radiation temperature.

The camera is characterised by an infrared permeable lens, a transmission line and a sensitive detector, which converts the thermal energy in thermographs called thermal images (Figure 1). Each image is a map of false colours that represent the various levels of infrared emission, from the higher value, which indicates the maximum temperature, to the lower value that is the minimum one.

Some basic requirements are necessary to assess the best thermal imaging camera solution.

- Camera resolution: is an important factor to determine the image quality and accuracy. The lowest resolution is 60×60 pixels that is also the cheapest solution. While 320×240 pixels resolution delivers superior image quality and 1024×720 pixels is the best resolution for more advanced inspections, with a wider field of view at longer distance observations.
- Thermal sensitivity: describes the smallest temperature difference that thermal camera can detect. The most advanced thermal imaging cameras for building applications will have a thermal sensitivity of 0.03 °C. Higher sensitivity is needed to capture more detailed images and better diagnosis.
- Accuracy: the current industry standard for accuracy is ±2 % / ±2 °C. The more advanced thermal imaging cameras have better accuracy: ±1% / ±1 °C.

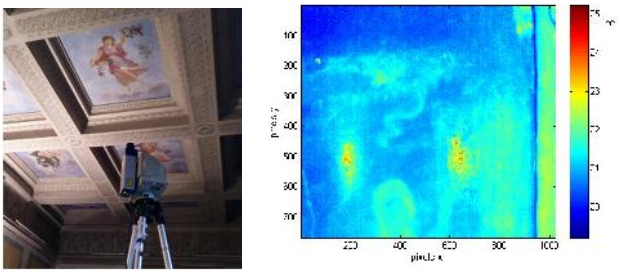

Figure 1. IR radiation received by the camera.

1.5.3.Main factors influencing temperature measurements

The results are based on some main factors to taken into account, as the emission properties of the target, the surrounding environmental conditions and the different kind of materials.

- Emissivity: In order to measure the temperature of an object using an infrared imager, it is necessary to estimate or determine the object emissivity. As seen above, each material has its own emissivity, which mainly range between 0.00 (completely not emitting) and 1.00 (completely emitting). For measuring the emissivity, there is a general procedure outlined in ASTM E1933-97[5] and ISO 18434-1:2008[6], which consist in measuring the temperature of the heated object under real working condition. In Table 1, the emissivity values of some reference materials are shown.

Construction Material	Emission Coefficient
Concrete	0.94
Sand	0.93
Brick	0.93-0.94
Limestone	0.96
Plaster	0.90-0.96
Glass	0.93-0.96
Wood	0.96
Felt(Roofing)	0.93
Gypsum	0.90
Paint	0.90-0.95
Clay	0.95

Table 1. Emission coefficients of construction materials

[5] ASTM E1933-97. Standard Test Methods for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers, 1997

[6] ISO 18434-1:2008. Condition monitoring and diagnostics of machines–Thermography– Part 1: General procedures, 2008

- Environmental conditions: IRT inspections need to consider the direct sunlight influence on the outside of a building. For better results it is also recommended to conduct the investigations when little or no wind and cloud cover are present.
- Time of data collection: different materials have different response to environmental temperature change that causes the variation of the objects radiant temperature during a 24-hour period. For this reason, the local sunrise and local sunset are the two preferred part of the day when the radiant temperatures of the materials are the same.
- Different kind of materials: the thermographic device has to know if there are outside or inside temperature changes before the inspection, as this can affect the temperature readings. For this reason, during a thermographic investigation different physical properties of the investigated material need to be considered, as the thermal (conductivity, diffusivity, specific heat) and spectral properties (emissivity, absorption, reflection, transmission), but also the porosity, volumetric mass, physiological water content.

1.5.4. Applications in cultural heritage field

In archaeological field, IRT is widely used for different investigation, ranging from historic building diagnostic and in situ structures inspection by means of passive thermography, to the analysis of other art and historic artefacts by means of active approach. The inspection can be conduct both externally and internally to the structure: the first one is more influenced by the external climatic fluctuations, while the second one has limited access due to external objects. Passive IRT used on historic building provides information about damp patches of the walls, in which the temperature is lower than the adjacent areas. This approach can be used for example to investigate the efficiency of specific cleaning treatments on certain architectural surfaces for maintenance and conservation (Avdelidis & Moropoulou, 2004).
Another application of passive approach is the detection of masonry texture under the plaster or other general hidden building components (NP & A., 2004). This is an important contribution to assess the quality of the restoration when a new material is introduced and must be compatible to the authentic materials, both in terms of colour and physical, chemical and mechanical properties.
For the identification of dump areas, the active IR approach is adopted. In particular, the thermal difference between defected and adjacent area is obtained by heating the inspected surface with external source, otherwise in steady state condition the temperature variation is not enough high to be detected. From structural defects, it is possible to distinguish the plaster-brick delamination, where the temperature gradient increases with the defect depth and it is possible to characterize the defect volume from the maximum time

of the thermal signal, by knowing the thermal properties of the material (Grinzato, Vavilov, & Kauppinen, 1998). Moreover, IRT can also identify the insulation deficiency phenomena that cause air leaks around openings (doors and windows) and at the junction between components, with a lower temperature respect to the adjacent areas (Fox, Coley, Goodhew, & De Wilde, 2014), or thermal bridges due to conduction losses. A general procedure for thermal bridge characterization is defined in the ISO 6781[7], which specifies a qualitative thermographic method to identify wide variations in the thermal properties on external surface of the buildings but cannot determine the degree of thermal insulation.

All these kinds of inspection are useful to determine the ageing and the degradation level of the materials, due to continuous exposure in the environment or inadequate use or absence of maintenance procedures. In addition, possible cause of degradation can be investigated with repeated measurements at certain time windows or after relevant atmospheric events.

1.5.5. Other Non-Destructive Testing techniques

Besides the thermographic method, in literature there are other techniques able to conduct non-destructive and non-invasive structural surveys, as the Ground-Penetrating Radar (GPR), Ultrasound and X-ray Fluorescence spectroscopy. In Table 2, all destructive and non-destructive methods are summarized based on the different kind of inspection.

GPR is a high-resolution technique that allows to detect small anomalies (changes of about centimetres) of subsurface (Pérez-Gracia, Caselles, Clapés, Martinez, & Osorio, 2013). The emitted and radiated signals are transmitted into the structure to detect anomalous variations (generally internal cracks) in materials with different permittivity and the receiving antenna records the return signal.

Ultrasonic velocity technique is a non-invasive method that uses pulse- waves (also called seismic waves) travelling with different velocities and/or amplitudes. By measuring the time required for the waves to travel from the sources to the receptors, it is possible to detect the thickness and the position of the damages and degradation zones, physical properties of the different materials, including mechanical characteristics and the state of cracking, fractures and other internal defects. In particular, it is very effective in detecting the modulus of elasticity but becomes unreliable in the presence of moisture and density (Kilic, 2015).

The X-ray Fluorescence spectroscopy (XRF) involves the irradiation of the investigated surface to the X-radiation and the corresponding spectrum returns both the material composition by the wavelengths of the

[7] ISO 6781: Thermal insulation – Qualitative detection of thermal irregularities in building envelopes – Infrared Method, 1983

emitted X-rays (qualitative) and the distribution of the characteristic elements by the intensity of those X-rays (quantitative). The main investigation by means of this technique is the characterization of ancient artefacts in order to obtain some information about the chemical composition of precious and unique objects. The portable Energy-Dispersive XRF spectrometers is widely used in the study of cultural heritage materials (Ridolfi, 2013). The main drawback of the XRF is that diagnostic test assumes a prior knowledge to identify and verify a particular process of the examined sample. In addition, the reproducibility is limited by the non-homogeneity of the sample and the difficulty of acquiring the object in the same position.

Kind of inspection	Method	Advantages	Drawbacks
Hidden spaces and cavities	*Endoscopy*	Simple and operative, easy to operate, real time inspection	Invasive, when inspecting larger cavities, the thin cable must be protected
	Ground-penetrating radar (GPR)	Fast and accurate allowing for locating, identifying and measuring subsurface structures.	Sounding depth limited in water environment, areas of high salinity, and moist sedimentary rocks, e.g. loam, clay.
	Active Thermography	Non-contact method, very fast method, area measurements, direct localization of defects	Expensive, unknown depth of defects, depends on weather conditions
Damage inspection	*IR Thermography (active and passive)*	Non-contact method, very fast method, area measurements, direct localization of defects	Expensive, low spatial resolution for large structures
	Acoustic tracing	Fast and low-cost method, efficient on any type of surface – rough, glossy	No substantial risk, need of manual operation and physical contact
	Resistograph	Designed for on-site use.	The length of the cable (about 60 cm) is sometimes limiting for measurement in desired direction.
	Ultrasonic technique	Easy to use also in on-site inspections: compact-size, lightweight, easy to operate, large display showing immediately measured time value	Unsuitable for layered or laminated materials. It is more reliable when placing the probes in an opposing position.
Material analyses	*Electrical Capacitance Tomography*	Easy to use, fast and inexpensive	Contact method: difficult use on rough and/or uneven surfaces, as often those of historic walls. The measurement location is not precise. All adjacent materials to the sensor affect the reading.

Electrical Resistivity Tomography	Non-invasive, low cost and easy to use	Measures are strongly influenced by the presence of salt, the contact pressure applied to the pins, the temperature, the hardness, the irregularities and the surface conditions of the investigated materials.
Fibre Optics Microscopy (FOM)	High resolution, high contrast magnified (up to 600×) images	Destructive, sample preparation is difficult, especially for a polarized light microscopy.
Passive Thermography	Non-contact method, fast and easy to use	Only qualitative survey, depends on the emissivity of the material.
Spectroscopic techniques • *FTIR*	High reliability, possibility to perform in-situ investigation	Destructive, specificity and interpretability of FTIR spectra may be limited due to overlapping bands
• *NMR*	High portability, on-site inspection, quantitative analysis	Destructive, not very sensitive, large and expensive instrumentation
• *EDXRF*	Rapid, cheap, completely portable and sensitive	Possible problems can arise from overlapping peaks derived from the elements of interest.

Table 2. Comparison between the different techniques for diagnostic survey in cultural heritage

<u>Cost:</u>

Costs for infrared cameras and the related software range between:

- 200 – 1000 € for low-end thermal imagery sensors, 80**×**320 px resolution (qualitative inspection);
- 1000 – 10000 € for mid-range camera sensors, 320**×**640 px resolution (qualitative and quantitative inspection);
- 10000 – 40000 € for high-end ones, over 640**×** px resolution (research and laboratory activities).

The costs for excitation sources adopted for active IRT investigation vary according to the applied method. In cultural heritage field, the following sources are generally used:

- 500 – 5000 € for optical flash, lamp and electrical heaters (conventional, pulsed and lock-in thermography).

For other applications:

- 1000 – 30000 € for optical laser (laser excited thermography);
- 500 – 10000 € for acoustic/ultrasonic horn, piezo-ceramic actuators, air-coupled transducers (ultrasonic stimulated thermography).

Cost of thermal investigation must be quantified according to the investigated scene, the number of required operators and the time required for the inspection.

2. Equipment

In general, the main equipment required for augmented-, virtual-, and mixed-reality systems are displays, computers, tracking cameras, input devices and sound systems.

2.1. Display

Presenting virtual content is perhaps the most essential aspect of immersive technologies. Presentation equipment are classified according to the kind of virtual content they are designed to display—visual, auditory, or tactile. However, to date, existing CH-related applications, have focused on visual presentation. There are six types of displays.

2.1.1. Head-Mounted-Displays (HMD)

Description:

The first, Head-Mounted-Displays (HMD), can be used for AR, VR, and MR experiences. The HMDs in AR can either be optical-see-through or video-see-through. Optical-see-though allows users to see part of the real environment through the lenses, while the video-see-through HMD supplies a view from video feeds supplied by multiple wearable cameras. Optical-see-though HMDs have to overlay real space to display the augmented view—users see synthetic content and the real environment coexisting in a virtual space. In the case of video-see-though HMDs, on the other hand, a computing device processes the images coming through the cameras mounted on the HMD, augments the scene with virtual information, and renders the blended images and this approach is therefore more demanding in terms of computation. Since the user sees the real environment through the cameras mounted on the HMD, video-see-through HMDs can trick human perception into believing that virtual and real environments coexist by introducing deliberate delay before rendering the blended image, thereby properly registering virtual information over the real environment. Such control over the registration process is extremely difficult with optical-see-through HMDs, because the user can see the real environment thorough the lenses, first-hand. In any case, the introduced latency must be very low, otherwise users will notice the time gap. HMDs in VR, on the other hand, are not see-through. These displays have been used in a wide spectrum of VR applications to present

3D virtual scenes to users. Such HMDs are connected to a computer for real-time and realistic rendering of virtual scenes. A user’s pose is tracked to correct the perspective of displayed images.

Minimum requirements:

N/A

Costs for VR devices

- *Oculus Quest*: equipped with battery, neither PC nor cables are required - 550 €
- *HTC VIVE pro:* PC required - 2300 / 2500 €
- *Oculus rifts:* PC required - 1800 / 2000 €
- *Google Cardboard*: only external smartphone required - 7 / 10 €

Costs for AR devices

- Vuzix Blade - 1500 / 2000 €

2.1.2.Spatial AR (SAR),

Description:

The second type of display, Spatial AR (SAR), layers virtual information directly on the real environment, either by projection using video-projectors or through holography. The first one relies on a very accurate calibration and do not requires a tracking system. The second one relies on robust low-latency markerless tracking. A recent AR project in the CH domain that use projected displays is the Revealing Flashlight. Applications of Holographic AR, on the other hand, are only now beginning to emerge due to the nascent technology and should be considered experimental, so that its development is entrusted on the availability of prototypes.

Minimum requirements:

- VideoProjector WUXGA 20.000 Lumens, and example can be the *BARCO HDX 20 FLEX equipped optics (ratio is case specific) like for example Sanyo LNS-W04 / Eiki AH-32401*
- Personal Computer *Core i7 (4th gen or newer), 16GB of RAM, GeForce GTX 1080 /or better), SSD, Windows 10*

Cost:

Generally, it is very expensive, so it should considered for rent 2000-5000€ per day

2.1.3.Hand-Held Devices (HHD)

Description:

The third type of display, hand-held devices (HHD), can be used for AR, VR, and MR experiences. It combines a digital camera, inertial and GPS sensors, and a portable display. These displays, when used for AR and MR experiences, use video-see-through approaches to superimpose virtual content over real environment views. Most AR research in the CH domain focuses on handheld displays. Handheld displays are also suitable for non-immersive VR systems. Recent advances in mobile technology, such as Samsung's Gear VR, have made it even more suitable for Immersive Reality.

Minimum requirements:

Smartphones or Tablet should fulfill the following features: Android Devices

- Quad Core CPU
- Memory: 1-2GB RAM (dependent on model size)
- Android Version: 6.0 (Marshmallow) or newer
- IMU w/ Gyroscope Sensors
- Selective Image Stabilization

Cost:

It is variable from 300 to 500 €

2.1.4.Desktop screen and projection

Description:

The fourth type of display, a desktop screen and projection, is mainly composed of a workbench, projector, and computer. These display systems are common in visualisation environments for non-immersive and semi-immersive VR experiences. With the addition of stereo glasses, desktop displays can provide 3D scene viewing functionality for multiple users. To correct the perspective, tracking methods can be employed to track pose, though tracking is not very often utilized in non-immersive and semi-immersive settings. Gesture-based and device-based interfaces are commonly implemented to allow interaction with the displayed virtual scenes.

Minimum requirements:

- Personal Computer Core i7 (4th gen or newer), 16GB of RAM, GeForce GTX 1080 /or better), SSD, Windows 10 and headphone support
- Monitor, 32 Inch 1080p Frameless Widescreen IPS Monitor with Screen Split Capability HDMI and DisplayPort
- Videoprojector standard, 3400 lm, full HD, contrast 15000:1

Cost:

It is variable from 1000 to 4000 €

2.1.5.Cave Automatic Virtual Environment (CAVE)

Description:

The fifth type of display, a Cave Automatic Virtual Environment (CAVE) and related technologies, is a polyhedral projection display technology that allows multiple users to experience fully-immersive and vivid 3D scenes. Multiple projection displays or screen walls—typically three to six—are conjoined to make up a cave like cube, in which users are situated to experience enhanced presence in fully immersive 3D virtual environment. A CAVE environment is such, only in case an interaction with the environment is foreseen. In other words, inside the box should be implemented tracking systems that are able to sense the presence of users. The interaction can be passive (only by moving inside the box the contents are consequently interactive) or active (the interaction is gesture-based).

Minimum requirements:

- n° 4 High Definition videoprojectors: 3-LCoS technology; resolution 1.440x900 pixel; 4.500 lumen; ratio 0.57:1
- Content Management Systems, 16GB SDHC, network switch.
- RGB-D Camera: i.e. INTEL Real Sense (RGB-D)
- Holding structure (dimensions are depending on the space available)

Cost:

It is variable from 80K to 300k €

2.1.6. Holographic projection

Description:

Through sophisticated image processing, holographic projection allows viewing of the 3D effect without the use of glasses. The result is that the technology, practically 'invisible', offers great spectacle even in bright environments. From the life-size hologram to the display system, there are various models and sizes.

Possible uses:

- For museums, theatres and events;
- Reproduction of a historical figure, reproduction of sculptures, objects, statues, theatrical performances;
- Communication messages in general;
- 3D presentation of its products;
- Three-dimensional simulation of an architectural project;
- 3D virtual exhibition of an unavailable original (ancient artefact, vase, jewel, building ...).

In the most advanced holographic systems interactive solutions are available thanks to which it is possible to interact with the three-dimensional object.

Minimum requirements:

A good holographic projection system must guarantee a good resolution and an excellent brightness, in order to allow the visualization even in not completely dark environments.

Cost:

The cost can should from € 8000 to € 80000 depending on the size of the hologram, the content and the interactivity (over 80 if it is a theatre hologram or customized with actors, etc.)

2.1.7. Seamless screen walls

Description:

This new generation of screen is introducing a whole new world of possibilities. Removing the grid of bezels:

- Removes the limit on the types of images that can be displayed

- Enhances visual appearance
- Prevents misinterpretation of the data/content
- Makes higher resolution possible
- Allows free use of the pixels

The seamless screen wall can be used in any number of ways, and it's the user who determines the particular usage. It provides the user with the artistic freedom of a blank canvas: regardless of the type of content. In addition to the excellent visual quality, the latest models are integrated with interaction systems.

Minimum requirements:

- High-definition
- Limited thickness
- Maximum consumption 800 w sqm
- Minimum duration 80,000 hours
- Unlimited wall sizes
- Can be installed on the ceiling and on curved surfaces

Cost:

The cost is very variable and depends on the screen size, resolution and required interactivity.

2.2. Computer

Description:

Computing devices are used in AR, VR, and MR to run the required software tools. From a hardware perspective, a state-of-the-art system is generally needed to generate and render realistic virtual scenes in real time. As little as a decade ago, it was common to use laptops and bulky bags that users had to carry when using the application in situ. These days, mobile devices, such as smart phones and tablets, are equipped with much better processing units and memory than high-end laptops from a few years ago. More than this, mobile devices typically incorporate a high-resolution display, inertial and touch tracking, and multiple cameras in a single small portable package, making them well suited to outdoor AR application.

Minimum requirements:

Personal Computer Core i7 (4th gen or newer), 16GB of RAM, GeForce GTX 1080 /or better), SSD, Windows 10 and headphone support

Cost:

It is variable from 1500 to 2500 €

2.3. Tracking Devices and Cameras

Description:

Tracking devices: Cameras are used for AR and MR applications that depend on marker based or markerless tracking. Camera and tracking devices are used in combination if a hybrid tracking approach is required. In general, the commonly used tracking devices are electromagnetic, acoustic, and inertial sensors. More in general, a tracking system is required when there happens any kind interaction by the user with the Virtual Contents. The tracking system in this case should be considered as the trigger for a specific interaction by the application. They can be contact or contactless. The following list of tracking devices is not exhaustive but embraces the main hardware components available and most used in the market.

Input Devices:

A range of input devices are available. To shift interaction interfaces from desktop-based Graphical User Interfaces (GUI) to more intuitive and natural ones, speech, gaze, and gesture sensors—including wearable devices, such as gloves and wireless wristbands—will substitute for conventional input devices. However, the choice of input device should depend both on the domain of the application and the system. In the case of AR applications that use mobile devices, input and interaction can exploit the touch-screen, microphone, and tracking sensors. More generally, the common input devices for interaction and input in VR applications are data gloves, gesture sensors, joysticks, mice, wands, gamepads, and some wearable haptic sensors.

The following list is not exhaustive, since the most commonly available devices are not included.

Minimum requirements:

N/A

Cost:

- Active Beacons: i.e. Estimote Beacons (SDK included) - 30 € cad

- RGB-D Camera: i.e. INTEL Real Sense (RGB-D) - 300 / 400 €
- Leap motion - 300 €
- VR bracelets: i.e. VR motion band - 100 / 200 €
- Eye tracking Tobii Eye-Tracker X2-60 ImotionsR + Attention Tool software - 50K€

3. Technology development

The contents and the equipment listed in the previous paragraphs constitute the DEs infrastructure. Below are presented some of the most common technological applications with a approximately range of development costs.

3.1. Web

Description:

Every innovation and research action is successful and achieve an important impact, if it establishes good connections with interested researcher and user communities. The web is important for exchanging information, keeping up to date with the latest developments and disseminating the results.

Nowadays, this can be best achieved through digital channels, such as traditional and social media but also through a web-platform. It has the advantage of being able to present information to a diverse group of people at the same time and on demand. It can not only provide basic information that is static but also deliver reoccurring and constantly changing pieces of information. The web-platform will enable users to look for specific content on the website and/or on mobile applications. All contents developed by the partners during the project will be made accessible on both the website and the mobile application.

It is structured with a front -end side, in which contents can be visualized and managed by the users, and the back end-side, that is the cloud based infrastructure which enable to upload the contents.

Minimum requirements:

N/A

Cost:

BackEnd:	7000 - 11000€
FrontEnd (web side):	4000 - 8000€
FrontEnd (mobile app side):	4000 - 8000€

3.2. Virtual Tour

Description:

The Virtual Tour is a simple but efficient tool to visit the spaces. It consists in the panoramic photos (scene) linked together, visible at 360° in immersive mode, and enriched by other metadata (popup), e.g. texts, sounds, HD images and videos.

Whether the photos are merged manually or automatically, we can modify, remove or create new merges, as well as change the position and orientation of the spherical photos, to ensure a realistic and uninterrupted viewing experience. When merging spherical photos, it's necessary that the unions created are between neighbouring observation points.

Do not try to create unions that disorient users who view your connected spherical photos for the first time. If you intend to add any form of attribution (watermark, information on the author and so on) to the zenith or nadir of your spherical photo, keep in mind the relative requirements indicated in the Text or graphics overlay section above.

A simple graphic interface allows to enjoy the 360 experience for all users, also not experts or not digital-friendly users (e.g. google maps, with few control and global icon). When it is possible, the virtual tour would have a marked map where the 360 view hotspots are shown. This allows to move in the interested panoramic photo, skipping the obligatory path.

Minimum requirements:

Each virtual tour should manage at least 1 and maximum 10 360° panoramic images, acquired with 360° cameras (i.e. Nikon 360°, Samsung Gear 360° or collected with cameras and then processed with stitching software with equirectangular projection). The platform permits (after the first upload that is up to the developer) to be autonomous in uploading panoramic images. Afterwards, in the platform the user can:

- visualise 360° images
- create 360° images
- create a path
- create a pin for opening contents (video, images, text, 3D models)

It is important to highlight that for cardboard the app should be developed ad hoc and that each device has its own application.

Cost:

For a Virtual Tour with the minimum requirements listed above the cost varies from 10000 to 14000 €.

3.3. Virtual Reality

Virtual Reality (VR), on the other hand, when fully exploited, completely immerses users in a synthetic world without any possibility of seeing the real environment, except through computer-generated representations. VR provides synthetic content to the senses in such a way that visual perception, hearing, and touch approach the experience of an actual environment.

Scene appearance and real-virtual combined modelling methods are common in cultural heritage VR applications, because the former focuses on representing the geometric aspects of real-word objects, and the latter refers to interfusing the computer-generated content and real world scenery to improve the efficiency and flexibility of VR modelling.

3.3.1. Non-immersive VR

Description:

These systems, as the name suggests, are the least immersive versions of VR experience. Such systems do not need a pose tracking method at all. The virtual environment is viewed through a desktop or handheld display. Interaction with the virtual environment can occur via device-based interfaces.

Minimum requirements:

The software tool allows to choose and visualise 3D contents, with the possibility to add (zoom, rotate, pin, touch). It consists of a Graphic Engine based on WebGL, JavaScript, and a Cloud repository. The number of models to be managed does not affect the final costs. The 3D model shall be realised to be compliant for the visualization and processing in Virtual Environment (depending of the complexity of the 3D model).

Cost:

7000 - 11000€ (including the cloud service hosting)

3.3.2. Fully-immersive VR (HMD)

Description:

Fully Immersive VR. Telepresence, which is a state of being fully immersed in a virtual environment, is the ultimate effect of immersion and interaction and VR systems that support this are called fully immersive. Immersing users inside a virtual environment is achieved by displaying a virtual scene from the user's perspective on HMDs and CAVEs. The ability to see one's surrounding physical environment is one of the aspects that differentiates AR from VR.

Minimum requirements:

For this kind of experience, it is mandatory to divide the creation of 3D environments in 3 Typologies.

- Real Environment (reality based): shall be provided 360° panoramic images
- Virtual Environment: a computer-generated 3D environment shall be provided
- Mixed Environment: 3D objects + 360° panoramic images (maximum of 15 panoramic images e maximum 1 3D model for each panoramic image).

Controls can be gesture based or not gesture based.

Cost:

Real Environment:	- 10000€ / 20000€
Virtual Environemt:	- 10000€ / 20000€
Mixed Environment:	- 12000€ / 15000€

3.3.3.Fully-immersive VR (CAVE)

Description:

However, this issue also comes into play with fully immersive VR systems depending on the display device—in the case of HMD-based VR experiences, one cannot see one's body, whereas a CAVE-based experience allows seeing one's body and even others situated in the CAVE. Natural interaction and being situated inside a virtual environment are the essential aspects of telepresence and both HMD-based and CAVE-based VR systems are viable approaches. Interaction during a fully immersive VR experience is best achieved by employing hybrid and multimodal interfaces as device-based interfaces may break user's immersion, because users will have to focus to some extent on the interaction devices.

Minimum requirements:

As per 3.3.2

Cost:

Real Environment: - 10000€ / 20000€

Virtual Environemt: - 10000€ / 20000€

3.4. Augmented Reality

Like Virtual Reality (VR), Augmented Reality (AR) is becoming an emerging platform in new application areas for museums, edutainment, home entertainment, research, industry, and the art communities using novel approaches which have taken augmented reality beyond traditional eye-worn or hand-held displays. Different from VR in which the real world is fully replaced with a virtual environment, AR does not replace the real world but augments a user's view of the real world with virtual objects.

New, application-specific alternative display approaches pave the way towards flexibility, higher efficiency, and new applications for augmented reality in many non-mobile application domains. Novel approaches have taken augmented reality beyond traditional eye-worn or hand-held displays, enabling new application areas for museums, edutainment, research, industry, and the art community.

AR needs tracking to superimpose virtual content over real environment views. Tracking in AR is needed to seamlessly register virtual content and real-world views in real time and correct the perspective to enhance users' presence in the real-virtual environment. It is important to distinguish between calibration and tracking; the former refers to determining an initial viewpoint and camera properties, while the latter refers to continuous re-evaluation of poses to accurately align assets. The practical effectiveness of registration is highly dependent on a tracking method's speed and accuracy.

3.4.1. AR Vision-based

Description:

Vision-based tracking, generally, tracks camera pose by detecting and recognising geometric features in the real environment to establish 3D world and 2D image coordinate correspondences. This approach can provide realistic real-time camera pose tracking. However, rendering virtual objects over the real environment could be slow due to the large amount of processing required. Unlike marker-based techniques—which are dependent on easily recognisable markers, markerless tracking depends on distinguishable geometrical features, such as building corners and edges.

Indoor AR makes use of either marker-based or markerless tracking, see-through HMDs, spatial or handheld displays, and tangible, collaborative, hybrid or multimodal interfaces. Indoor systems do not need GPS, but if the display is an HMD, then the system might use inertial sensors to track the user's viewpoint.

Minimum requirements:

For image based tracking, Min 5 POIs and Max 10 POIs

Cost:

The range of the costs are related to the purchase of an ad hoc SDK.

From 3 to 5 POI: - 8000€ / 9000€

3.4.2. AR Sensor-based

Description:

Sensor-based tracking uses a digital camera, vision algorithms, and easily recognisable landmarks placed in indoor or outdoor environments—these fiducial markers could be passive (printed markers) or active (IR emitting).

Inertial tracking is a navigation system that uses gyroscopes and accelerometers to measure the rotation and motion of a given target, thereby enabling the calculation of pose and velocity. The accelerometer measures linear acceleration to calculate the position of a target relative to some initial point. The gyroscope, on the other hand, measures angular velocity to calculate the angular rotation of a target relative to some initial orientation. Hence, the pose of a target is the integration of the measurements from the accelerometer and the gyroscope. This tracking method is inexpensive and can provide high update rates with low latency. However, it suffers from positional drift as a result of the accumulation of small measurement errors from the accelerometer and the gyroscope. Thus, relying on inertial tracking alone to estimate the position is problematic.

Outdoor AR relies heavily on markerless and hybrid tracking, handheld displays, and tangible interfaces. Optical-see-through HMDs and collaborative interface are used in some cases.

Minimum requirements:

There is no limitation in the number of Geolocation POIs

Cost:

The range of the costs are related to the purchase of an ad hoc SDK.

Does not exist a native SDK, so the price includes the SDK costs: 8000 - 12000€

3.5. Sensible spaces (city/museum)

Description:

The term Senseable Space defines these kinds of spaces capable of providing users with contextual services, to measure and analyze their dynamics, and to react accordingly, in a seamless exchange of information. The development of such environment is required in order to make it aware of and "Senseable" of human presence. The installation is done by pairing a mobile applications with IOT devices (e.g. Beacons localization technology based on Bluetooth Low Energy technology). The interactive solution suggests the user to follow the visit following the directions that arrive automatically from the Beacons that are located near the main attractions of the permanent installation or to specific POIs in case of urban environments.

The user is invited to explore the area, and guided by the Beacons, he/she visualise multimedia contents on the display of the device. Every time the user approaches a meaningful object, he is recognized by the system that offers an explanation. The system permits also to collect meaningful data about the users, about their behaviour, providing statistics to understand the real performances of an installation or of a certain area.

Minimum requirements:

Interaction with a minimum of 5 beacons with notification

Cost:

5000 – 9000 €

3.6. 3D print

Description:

Increasingly in recent years, 3D printing is at the service of cultural heritage. A very important advantage of 3D printing is that of making the exhibits of the museums touchable, addressing an audience of blind and partially sighted people.

The additive technology, which is the basis of the most widespread 3D printers, prevents the object from being born and growing on a work surface, from below (in the case of the FFF) or from above (in the case of the SLA), depositing gradually layers of material one after another.

It can therefore be said that additive technology is affected by gravity.

Moreover, 3D printers have their own construction mechanics, which is based on Cartesian axes rather than on laser instruments, so it is subject to the movement limits given by the presence of rods, motors, belts and so on.

Construction and operating specifications will determine the success of a modelled piece: for an FFF printer the "limit" is given by the size of the nozzle used and by the minimum distance of movement in the x, y, z axes, for an SLA printer it is necessary to consider the size of the laser and the pitch on the z axis.

Another subject is the slicing software. These software interpret the model and "reconstruct" it, creating a special file (usually a .gcode) composed of all the instructions necessary for the printer to spread the layers of material correctly. Such software, whether free, commercial or proprietary, must be able to correctly read the three-dimensional model, in the opposite case, problems occur such as false surfaces, holes in the geometry and, in the worst case, completely missing parts.

To contain printing costs, it is important to start from a good model, designed for the purpose.

Minimum requirements:

As mentioned in paragraph 1.4, not all models can be printed. When a mesh has problems, the slicer can incur serious errors in interpretation, causing the printing process to fail. It is sufficient to keep in mind some tricks when preparing a 3D drawing for printing, because this respects the modeling standards, resulting in an immediate saving on the cost of realization.

The 3D models created for printing must be completely closed: imagining to fill it with water, this must not be able to go out anywhere. Another very important aspect is how the orientation of normal versors is defined for each triangle within the STL file. All triangles must have the normal pointing to the outside of the object. If the model defined in the STL file contains an inverted normal (ie pointing in the opposite direction) the interpreters (including the 3D printer) are no longer able to determine which is the internal and which is the external part of the object.

Furthermore, it is essential to pay attention to the maximum size that objects can have in order to be entirely printed by the 3D printer we are using. Once the STL file has been tested and eventually repaired, the model can be sliced for g-code generation and then passed on to the press. To do this, we will need to use a slicing tool, so that the 3D geometry of a 3D model is subjected to a conversion of G-Code instructions, necessary to generate a toolpath for the extruder. Finally, the 3D model takes shape thanks to one of the many 3D printers controlled in turn by a control program, such as Fictor, Cura and Simplify 3D.

Cost:

The cost is too variable to be defined, it must take into account:

- model editing
- slicing
- material cost
- duration of printing
- size of the final prototype

It can range from a few tens of euros to a few thousand.

Abbreviations

VM= Virtual Museum

PP= project Partner

POI= Point Of Interest

DE= Digital Experience

AR = Augmented Reality

VR= Virtual Reality

SAR= Spatial Augmented Reality

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