PUBLIC-PRIVATE PARTNERSHIP

5G smarT mObility, media and e-health for toURists and citizenS

Deliverable D4.1
Robotic, Media and Smart Cities solutions for Touristic Cities

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List of Acronyms and Abbreviations

Acronym	Description
3D	3 Dimensional
3GPP	Third Generation Partnership Project
4K-HDR	4K High Dynamic Range
5G	5th Generation mobile Wireless Communication System
5G PPP	5G Public Private Partnership
5GC	5G Core
A/V	Audio-visual
API	Application Programming Interface
APN	Access Point Name
AQI	Air Quality Index
AR	Augmented Reality
ATE	Augmented Tourism Experience
BMSC	Broadcast Multicast Service Center
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPU	Central Processor Unit
DC	Datacenter
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
eNB	Evolved Node B
ENM	Ericsson Network Manager
enTV	Enhancement for TV Service
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
FeMBMS	Further evolved Multimedia Broadcast Multicast Service
GAM	Modern Art Galley
GDP	Gross Domestic Product
GPU	Graphics Processing Unit
gNB	5G Node B
HDR	High Dynamic Range
HPHT	High-Power High-Tower
HSS	Home Subscriber Server
ICT	Information and Communication Technology
IFB	Interference Free Band
IIT	Istituto Italiano di Tecnologia
IoT	Internet of Things
KPI	Key Performance Indicator
LED	Light Emitting Diodes
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
MAO	Museum of Oriental Arts
MAUA	Museum of Augmented Urban Arts
MBMS	Multimedia Broadcast Multicast Service
MBMS-GW	MBMS Gatway
MEC	Multi-Access Edge Computing
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MR	Mixed Reality
NB-IoT	Narrow Band IoT
NO_2	Nitrogen Dioxide
NR	New Radio
NSA	Non Standalone
O_3	Ozone
P2P	Peer-to-Peer
QoE	Quality of Experience
QoS	Quality of Service
RAI	Radio Televisione Italiana
RAN	Radio Access Network
RGB	Red Green Blue
ROS	Robot Operating System
SGI	LTE interface to the Packet Data Network (PDN)
SLAM	Simultaneous Localisation and Mapping
SO_2	Sulfur Dioxide
STEAM	Science Technology Engineering Arts Mathematics
TV	Television
UC	Use Case
UE	User Equipment
UI	User Interface
UNESCO	United Nations Educational, Scientific and Cultural Organization
URL	Uniform Resource Locator
UWB	Ultra Wide Band
VR	Virtual Reality
WP	Work Package
XR	Extended Reality

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Executive Summary

5th Generation cellular network (5G) is expected to be the communication technology that empowers a radical shift from a horizontal service model to a vertical one, where telecom network services are tailored to the specific vertical use case needs they address. 5G-TOURS will deploy full end-to-end trials to bring 5G to real users in many representative scenarios.

The magnitude of the touristic sector in Europe and the value created to tourists by these services provide an ideal platform for the creation of economic value and potential for high impact within Europe's economy.

The objective of this Work Package (WP) is to implement the touristic city use cases (UC) that will demonstrate the 5G technology benefits to citizens and tourists by providing added value services within the visited touristic attractions as well as media applications to complement their visit.

This WP (WP4 – Touristic city use cases implementation) addresses the deployment and validation of the touristic city use cases hosted in the Turin node related to enhanced museum visits (VR Virtual Reality support and robot-assisted tours), smart city applications (such as management of large crowds), interaction with robots, as well as links with life-long education and broadcasting of media contents (high quality video even with remote and distributed production).

This deliverable reports on the set of identified use cases for the touristic city (media production and distribution, safety and security in smart cities, museum and education, robotics) and their implementation on the 5G-TOURS platform within the Turin site.

The Touristic City of 5G-TOURS is a place where visitors of museums and outdoor attractions are provided with 5G-based applications to enhance their experience while visiting the city. This includes Virtual Reality (VR)/ Augmented Reality (AR) applications to complement the physical visit with additional content, involving interactive tactile communications. The visitors' experience is further enhanced with robot-assisted services, telepresence to allow for remote visits, as well as live events enabled by mobile communications such as multi-party concerts.

The scope of this deliverable - which is the first document of WP4 - is to describe the identified five vertical use cases from the "end – user"[1] point of view, as well as to list the main phases and components of the trial, which will be then further investigated and detailed in the operational design phase.

To deploy the envisaged use cases, 5G-TOURS initially exploits the facilities built within the 5G-EVE project, which is one of the three European ICT-17 projects in charge of building end-to-end facilities to support a variety of vertical field trials of which the "Touristic city" UCs are some of the possible applications. In the second phase 5G-TOURS will evolve its network infrastructure in accordance to UCs needs and network components availability.

Turin "Touristic city" site will develop and test 5G-enabled services regarding the following use cases:

- UC 1 - Augmented tourism experience
- UC 2 - Telepresence
- UC 3 - Robot-assisted museum guide
- UC 4 - High quality video services distribution
- UC 5 - Remote and distributed video production.

[1] i.e. the tourist that visits the city and its museums and attraction, accesses to the media broadcast, etc.

1 Introduction

Deliverable D4.1 falls under WP4 which interacts with:

- WP2 – Use cases design for the definition of the involved use cases,
- WP3 – Network architecture and deployment for the selection of the technologies to be deployed and the actual deployment of the trials,
- WP7 – System Integration and evaluation for the evaluation of the overall achieved results,
- WP8 – Business validation and exploitation for their impact on techno-economic plans.

Relations are also established with WP5 – Safe city use cases implementation and WP6 -Mobility-efficient city use cases implementation to align the expected activities with the rest of use case trials as well as to evaluate possible interactions and interworking opportunities among the different sites.

In this deliverable, the peculiarities and the main characteristics of each use case are highlighted and analysed. For each UC deployed on the Turin node this deliverable provides:

- UC description from the end-user perspective;
- indication of UC application components, i.e. all developments and prototypes needed for the vertical service implementation and delivery described by the industrial partner that develops the specific solution;
- description of the network elements required by the UC provided by the partner Mobile Network Operator (MNO) and Radio Access Network (RAN) vendor;
- description of the trials to evaluate the UC (including test setup and materials involved).

Detailed UCs descriptions are provided in Chapter 3.

The locations of the Turin node, chosen for UC trials, are shown in Chapter 2, where it is possible to see which experiences are accessible in each location and to which UC they refer. The locations have been selected for a variety of cultural experiences in order to showcase how the 5G technology can improve them and make them more accessible to everyone. They have also been identified as beneficial trail locations considering the commitment of the owners/managers, technical conditions, current 5G network coverage and expansion plans. During the operational planning phase, minor adjustments and alternative locations could be identified to cope with future – so far not predictable - conditions. The Turin node and its locations are described in detail in Chapter 2.

For the development and trial of the envisaged UCs on the Turin node, 5G-TOURS leverages indoor and close surroundings pre-commercial network deployment provided by 5G-EVE project (Phase 1) [14], as well as outdoor wider coverage of TIM's commercial network deployment (Phase 2); the specific technologies and the ad-hoc customization of the 5G platforms provided by the 5G-EVE project, as well as the specific modifications and extensions requested by 5G-TOURS objectives, are in the scope of this WP for the managed use cases.

5G-TOURS network description, its adaptation, extensions and additional components required for each UC are provided in Chapter 4.

Finally, Chapter 5 provides the UC's time plan and general trials evaluation methodology aligned with the work developed in WP7, to assure homogeneity of the assessment of each project trial covered by the implementation WPs 4, 5 and 6.

2 Touristic city - Turin

Lively and elegant, Turin is an incredible city set in the heart of verdant areas. Gently resting on the hillside and enclosed by the winding course of the River Po, it owes much of its charm to its enchanting location at the foot of the western Alps, watched over by snowy peaks.

Turin, the first Italian capital, allows visitors to discover its ancient and modern history through its palaces and museums, the parks and tree-lined avenues, the river and the hills, the restaurants and historic coffee houses, the long colonnaded streets and the multiethnic neighborhoods, in a balance between the traditional Roman town layout, the measured pomp of Piemonte baroque and the originality of the modern and contemporary architecture.

Figure 1 – Turin Landscape with Mole Antonelliana, Pixabay, 2019

Indeed, Turin and its surroundings offer visitors and tourists more than fifty attractions including museums, cultural heritage places, castles, residences and exhibition centers which, as a whole, represent an international cultural offer. Among these, it is worth to at least mention:

- the Royal Residences, declared a World Heritage Site by UNESCO,
- two thousand years of architecture and contemporary design,
- important churches, places of worship and the Mystery of the Holy Shroud,
- contemporary art in all its forms.

This rich heritage has its roots in the Savoy dynastic collection, which had increased a public organizational structure since the first half of eighteenth century. Thanks to this strong heritage as well as to its new vibrant innovation vocation, Turin is becoming an increasingly desired tourist destination.

Indeed, the Piedmontese capital in recent years has become more and more attractive for Italian and foreign tourists. Tourism in Turin shows increasingly encouraging data. The latest confirmations come from Federalberghi (July 2019) which released data on the number of visitors and hotel room rates. These data show that the tourism sector alone is worth approximately 7% of the regional Gross Domestic Product (GDP).

The numbers have been on the rise for ten years now, but it is in the first two quarters of 2019 that Turin has recorded a growth higher than all the other Italian cities, marking a + 5% against the increase of only 3% in Milan and the decline of 3% of cities like Florence. 70% of tourists come from the rest of Piedmont and other regions of Italy, but foreigners are also on the increase, especially from the United Kingdom (+ 18.4%), France (+ 15.8%) as well as from Germany (+ 5.2%).

As stressed in the Annual Report of Piedmont Observatory, in 2018, all of the Metropolitan Museums records a total number of visits that almost reach 5.2 million while the total number of visits in the rest of the region is just over 1.36 million. It should be underlined that the public visit data alone cannot be sufficient to understand the value of the museums cultural offer but has to be considered useful information to keep track of the evolution of museum demand on metropolitan area.

Another interesting aspect to be considered is the analysis of the seasonality of the flows, also in 2018, which cyclically finds a peak in spring and during the month of August. This data can be considered a starting point reflection to investigate the potential development of cultural tourism in "short trips" as well as the relationship that the museum system can establish with schools and education. In March for example, a period in which school visits are traditionally carried out, they get to reach the 20% of the total admissions registered in Piedmontese assets [7].

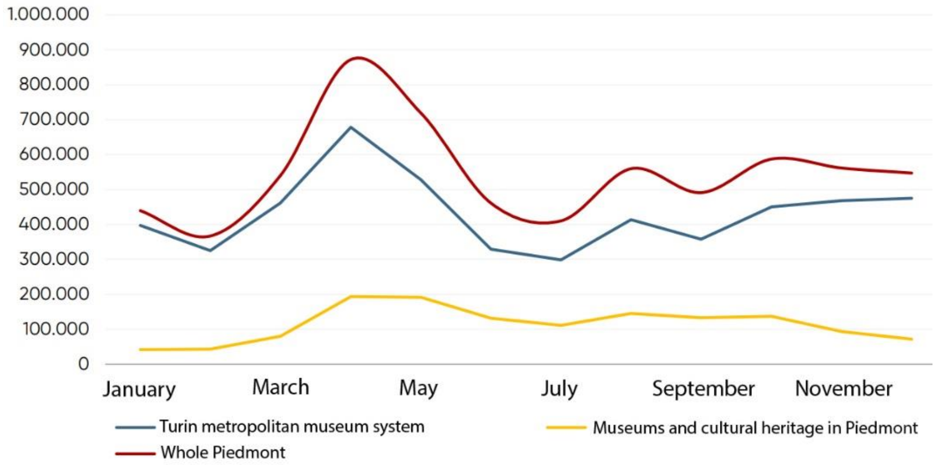

Figure 2 – Monthly trend of museum and cultural heritage entries during 2018 [7].

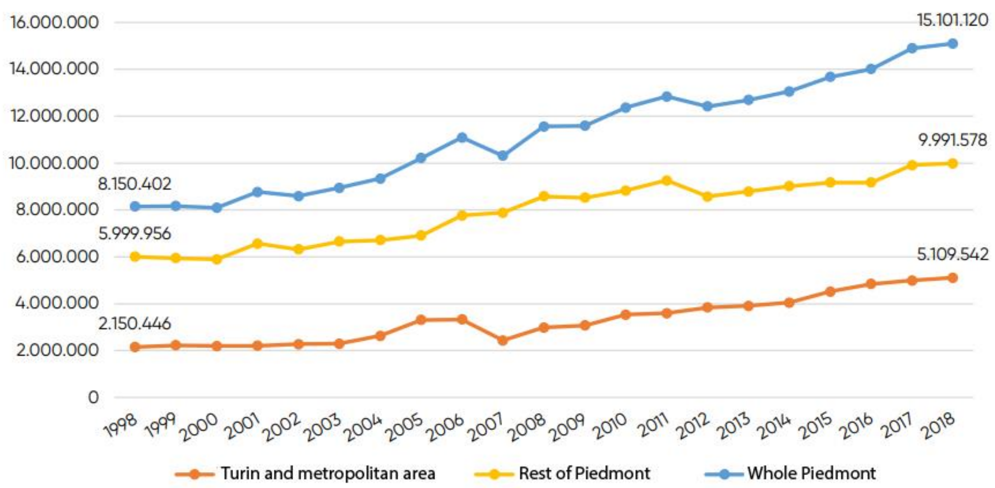

Figure 3 – Tourist presence from 1998 to 2018 [7].

About creative cultural production, in 2018 the cultural and creative production system in Piedmont was characterized by the presence of 21000 companies operating in the regional territory that have occupied about 85000 employees, generating an added value of just over € 5.63 billion, equal to 4.7% of the total amount produced from the regional economy.

In 2019 the number of companies operating in different areas is slightly decreased, compare to 2018. However, employment rate is slightly increased (+ 1.3%) and the economic dimension (in terms of added value produced) also registers a positive trend (5.7%). Generally, these trends demonstrate the consolidation of the realities already active on the market, but also of difficulties to increase the entrepreneurial birth rate.

These data are challenging and push the City administration, together with other local public authorities and private Foundations to develop integrated policies aiming at developing a renewed, improved and technology enhanced cultural offer towards both its citizens (with an emerging focus on schools and young generations) and tourists from Italy and abroad. This aim goes hand in hand with the economic development and innovation policies, where the focus is to boost the growing sector of culture and creative economy, with a strong focus on improved and immersive experiences enabled by technology, where 5G can play a strong role to this respect.

In more detail, it is worth mentioning the Turin innovation policy called "Torino City Lab" [8], a platform-initiative aimed at creating simplified conditions for companies interested in conducting tests in real conditions of innovative solutions for urban living. Torino City Lab is conceived as an open laboratory of frontier innovations enabled by the public administration and is expected to attract companies and skills to guide the development of the "City of the future". Torino City Lab involves a vast local partnership of subjects from public and private sectors interested in supporting and growing the local innovation ecosystem. Currently, one of the focus areas is "innovative urban services enabled by 5G technologies", including city applications of artificial intelligence and collaborative robotics, Internet of Things (IoT), AR and VR. More recently, within Torino City Lab a dedicated laboratory for learning technologies called "Edulab" has been launched, that allows testing activities with schools for innovative programs embracing also arts, theatre and culture through the deployment of extended reality (XR) experiences.

Taking into account this favorable context, the "Touristic city node" will try to develop complementary and linked trials for different use cases, based upon the following general principles:

- Offer an overall integrated indoor and outdoor immersive experience to the visitor/citizen.
- Assure the possibility to enjoy these immersive experiences through any possible device, that fits the different context and final users.
- Promote the use of "technology for all" making touristic visits easy to experience and accessible, with particular attention to disadvantaged people and disabled.
- Provide sustainable conditions for testing and scaling.
- Develop use cases able to challenge the performances of future 5G networks as well as blend functions (e.g. learning and culture, surveillance and tourist services).

The main use cases and its current identified locations are described in Table 1.

	UC1 Extended Reality	**UC2 Telepresence Robot Remote Control**	**UC3 Human Robot Interaction**	**UC4 Video/audio access and distribution**	**UC5 Video/audio content production**
Main Locations	Palazzo Madama; GAM; Edulab Other locations investigated: Borgo Medievale, Museo Pietro Micca and Risorgimento Museum	Palazzo Madama; GAM; Edulab Other locations investigated: Borgo Medievale and Museo Pietro Micca	Palazzo Madama; GAM	Palazzo Madama and surroundings	Palazzo Madama and surroundings 5G-EVE Mile of technologies and the auditorium Arturo Toscanini Other location investigated: Around the city of Turin and museums involved in the trials

Table 1 – Experiences locations

These locations enable the conveyance of different "stories" and experiences. This will enrich the testing potential towards the different targets and will enable a good coverage of the most important cultural locations in Turin.

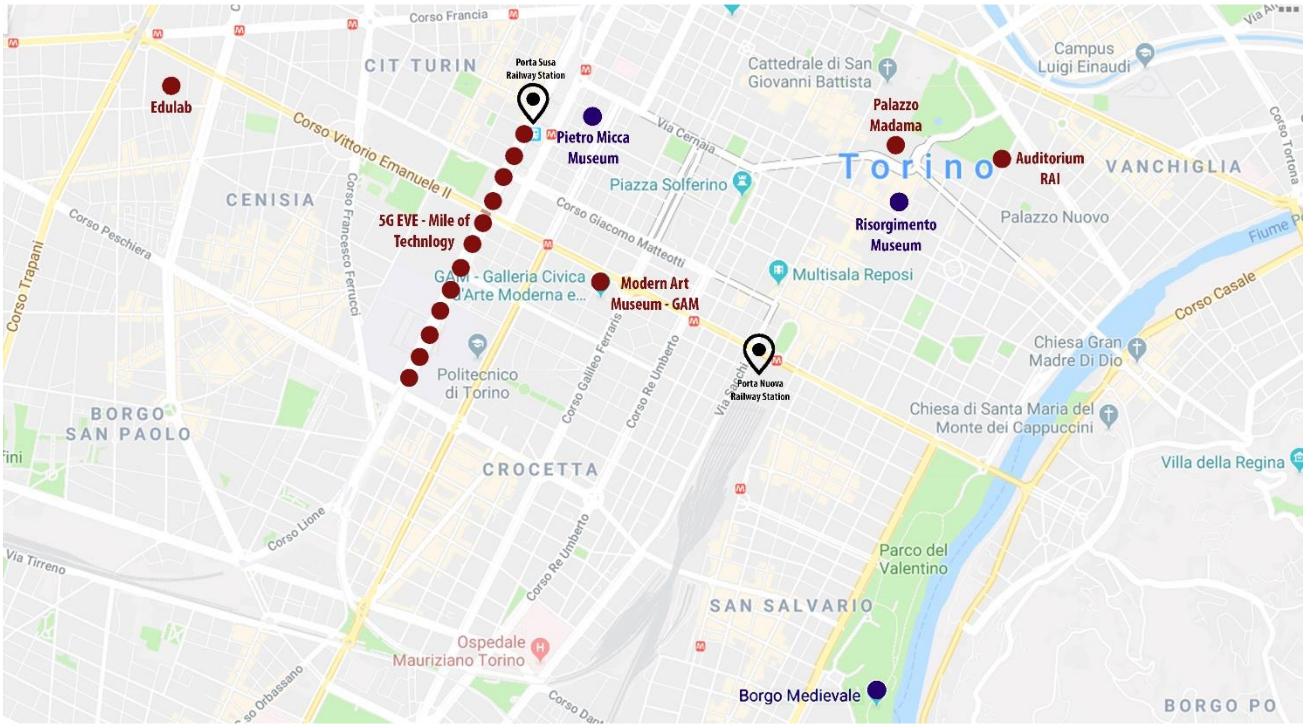

Figure 4 – Turin Node "Touristic City", City of Turin, 2019

Generally, the main target of each testing activity will be the tourist, but other categories include:

- School community (student, teachers, families);
- Citizens in general;
- Cultural Building managers.

Finally, it is worth mentioning that in order to enlarge the scope and impact of 5G-TOURS testing activities, the City of Turin will try to link them as much as possible to current initiatives targeted for citizens and enterprises. On one side, all the "Technology-enhanced" cultural experience developed will be made accessible and publicized to final users thanks to a unique online access point: Turin Museums Portal [9] which is currently under renovation. On the other side, testing activities of 5G precommercial solutions and services will be complemented by networking and supporting activities within Torino City Lab in order to further boost the augmented tourism economy. For instance, the City of Turin could also launch dedicated "Call for testing" for 5G-enabled solutions in this field within the project timeline, as well as "Call for ideas" targeted to students and developers.

To conclude, investigating the potential of 5G enabled services in the cultural sector is perceived not only as way to improve the cultural offer, but also to showcase how technology can promote a renewed storytelling for Turin City Branding: a City of History and Culture, a strong Industrial past, now devoted to be a place to innovate.

2.1 Palazzo Madama – Civic Museum of Ancient Art

Palazzo Madama (Figure 5) is an architectural and historical complex located in the central Piazza Castello in Turin. It is an UNESCO World Heritage Site, as part of the Savoy Residences serial site. Today the building hosts the Civic Museum of Ancient Art and represents itself as a summary of all the historical age of Turin: (i) the Roman era represented by the ruins basement, as the Palazzo was built on the premises of one of the Roman gates to Augusta Taurinorim, (ii) the middle age era, with the Casaforte di Casa Acaja, and (iii) the baroque era, as a symbol of the power and prestige of the “Madame Reali”, Cristina of France and Maria Giovanna Battista of Savoy Nemours. In the XIX and XX centuries, Palazzo Madama was turned into a city museum thanks to a series of bold and visionary directors, like Emanuele Tapparelli d’Azeglio, that shaped the collection and the mission of the museum. The museum experience consists in a two-to-one tours. The first tour concerns the history of the building, and the second one concerns the works of art it contains. Improving both approaches through the use of innovative technologies can represent an important step forward for one of the main internationally recognized and most visited museum of the City.

Figure 5 – Palazzo Madama, Fondazione Torino Musei.

2.2 GAM – Civic Gallery of Modern Art

The Civic Gallery of Modern and Contemporary Art of Turin (Figure 6), better known as GAM Turin, was founded in the last decade of the nineteenth century. The gallery's permanent collection currently consists of works from the nineteenth and twentieth centuries. Turin was the first city in Italy to engage in the public collection of modern art creating its own Civic Museum, officially opened in 1863. At the end of the 1980s, the building was closed to the public and reopened several years later, in 1993, following the restoration work that expanded the exhibition area and made it accessible to a public with problems of mobility. The heritage of the Gallery currently contains over 45,000 works including paintings, sculptures, installations and photographs, as well as a collection of drawings and engravings and a vast collection of artist videos, making it one of the most important collections in Europe. GAM also host a dedicated space for educational activities targeted to schools and families.

Figure 6 – GAM, The Building, Fondazione Torino Musei.

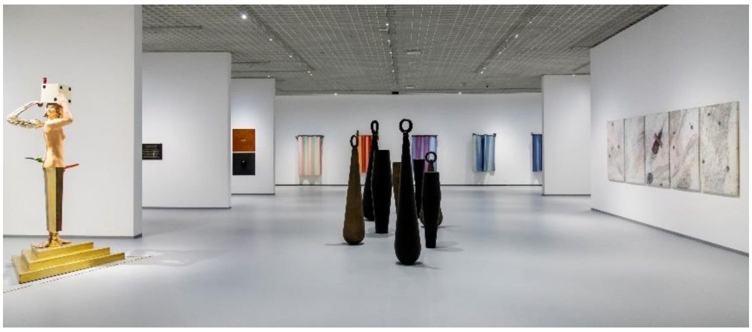

Figure 7 – GAM, Collections

2.3 The Educational Lab (Edulab)

The Educational Lab (Edulab) (Figure 8), recently launched within Torino City Lab initiative [8] is conceived as a space dedicated to innovation in the educational field, in order to allow the testing of solutions in teaching and learning environments. These equipped spaces into the Drovetti School (Torino Via Bardonecchia) will be dedicated to workshops, open to all schools with the guidance of experts, and with the active role of citizens, students and teachers interested in experiencing first-hand educational experiences.

Among the different sectors, there is an interest to link education and culture, and thus promote innovative learning experiences in the STEAM (Science Technology Arts Engineering Mathematics) area for students of 6 to 18 years old. Indeed technology and 5G can enable innovative extended reality learning experiences as well as gamification and collaborative learning among different schools and museums through robotics and telepresence.

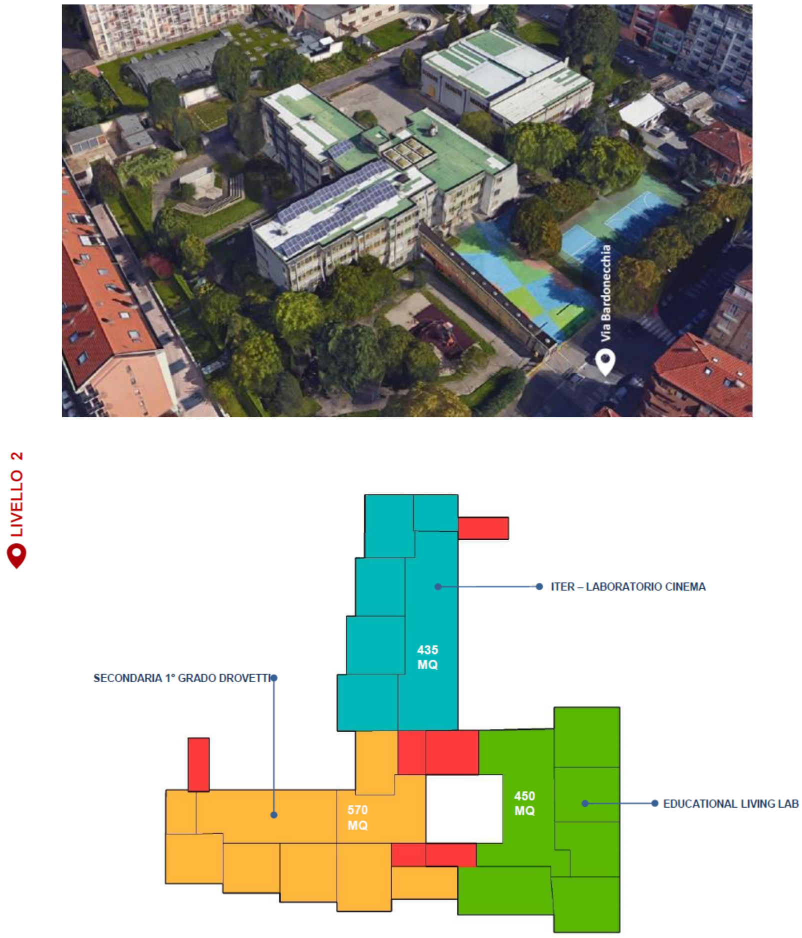

Figure 8 – Edulab, City of Turin

2.4 Auditorium RAI Arturo Toscanini

The Radio Television Italiana (RAI) Auditorium of Turin "Arturo Toscanini" is a structure of RAI in Turin (Figure 9). Built at the end of the nineteenth century to host equestrian representations, it was radically restructured several times during the twentieth century. Since 1952, it has hosted the RAI Orchestra of Turin and since 1994 the unified RAI National Symphony Orchestra. It also hosts regular symphonic seasons and high-level concert events. Currently the structure has a choir, a large audience, a gallery and a balcony arranged in a horseshoe shape, for a total capacity of 1,616 spectators. In 2007, on the occasion of the fiftieth anniversary of the Italian composer disappearance, the auditorium was named in memory of Arturo Toscanini. It represents one of the main sites of cultural tourism hosting several international events every year.

Figure 9 – Auditorium Rai Arturo Toscanini, RAI.

2.5 5G-EVE Mile of Technology

The 5G-EVE Mile of Technology is the place where the 5G-EVE project technologies were installed, and represents a particularly important axis for the city of Turin, obtained on the path of the ancient railway passer. The railway represented an insurmountable limit between the city center and the neighboring districts. The avenue (Figure 10) was obtained thanks to the bury of the rail path and has become a major link between centers of innovation and culture: the new Porta Susa station project and the San Paolo skyscraper built according to the most innovative energy saving principles, the Museo delle Carceri Nuove and O.G.R. (old locomotive repair shops) as new cultural and innovation centers, the expansion of the Polytechnic area as research and innovation center as well as technological private industries such as General Motor center. In this perspective of innovation and change the experimentation of advanced 5G infrastructures is placed.

Figure 10 – 5G-EVE "Mile of Technology" – VR/AR Applications developed, Politecnico of Turin

2.6 Other locations

In this section the description of the additional possible locations in which the UCs could be developed is reported.

2.6.1 Pietro Micca Museum

The Pietro Micca Civic Museum (Figure 11) was established in 1961, on the occasion of the celebrations for the centenary of the Unity of Italy. This particular museum is dedicated to the Siege of Turin of 1706, and gathers a collection of memorabilia, reports, documents and representations related to this important historical event. Micca sacrificed his life to blow up a mine in a tunnel that blocked the siege of French troops, who had entered underground tunnels, definitively changing the outcome of the battle. It is considered one of the most interesting and significant museums of war history in Italy. Indeed, a visit to Turin Pietro Micca Museum is a journey into the past, back to the days of the Spanish Succession War (beginning of the eighteenth century), when Turin was besieged for four months by the French army. The town was saved by the so-called "war of mines" which was fought across a vast network of tunnels extending under and beyond the external defense works. At least nine kilometers of galleries have been entirely preserved throughout the centuries, and can be visited today, representing an absolutely unique example worldwide. In more recent years, during World War II these same galleries were used as anti-aircraft shelter. The museum offers an engaging and interactive experience, and is therefore easy to imagine how the use of new technologies can facilitate an immersive storytelling starting from a real visit of historic places. Experiments have already been made to allow remote visits for the scarcely accessible tunnels/places within the Museum. The idea is to also valorize in situ experiences through innovative virtual guides, interactive visits and gamification.

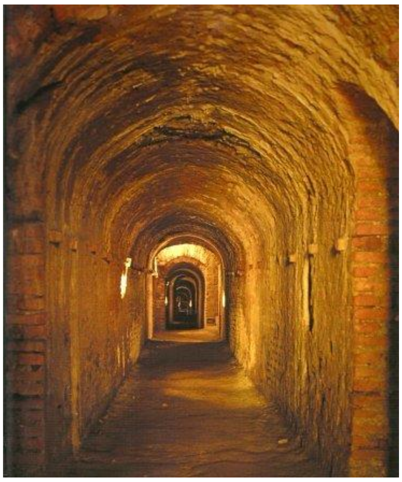

Figure 11 – **Museo Pietro Micca, City of Turin**

2.6.2 The National Museum of Italian Risorgimento

The National Museum of the Italian Risorgimento hosted in Palazzo Carignano (Figure 12) offers outstanding displays and services in to visitors where the collections are housed. The period of the Risorgimento is recounted from a European viewpoint as well as through the eyes of Turin, Piedmont and Italy. The rooms are enriched with films created with images from the most important European collections, and can be viewed on large screens, while extensive interactive displays help visitors examine the themes presented in the films in greater depth. Palazzo Carignano hosts the first Parliament House, and generally, the Museum curators hold original objects, paintings, documents, speeches which can witness that relevant period for Italian history.

Here, 5G enabled XR experiences could help to recreate a parliamentary debate before the Unity of Italy, starting with the existing laser scan of the "Parliament House".

Figure 12 – **National Museum of Italian Risorgimento, City of Turin**

2.6.3 Borgo Medioevale

The Borgo Medioevale of Turin (Figure 13) is an open-air museum that rises along the Po river, in the Valentino park in Turin. The medieval Borgo and Fortress of Turin constitute a unique museum dedicated to medieval architecture. In 2016, the museum complex reached 145,000 visitors. It was created in 1884 in the Valentino Park, as a section of Ancient Art of the Italian Universal Exhibition of Turin, to reproduce a feudal village of the fifteenth century. The buildings, decorations and furnishings were faithfully reproduced starting from Piedmontese and Val d'Aosta examples of the fifteenth century. Historians, technicians, connoisseurs and artists, including the architect Alfredo D'Andrade, were called to collaborate in the commission charged with the study and planning of the Borgo.

"Enter in this location" means traveling through time and space, leaving the city of the 21st century. The visit of the medieval village can be divided into two parts: the first involves the lower part of the Borgo, almost at river level, while the second leads to the castle and the garden. The use of 5G technologies can increase the perception of historical places ensuring a full immersive experience.

Figure 13 – Borgo Medievale, City of Turin

3 UCs detailed description

In the next sections each UC is deeply analyzed starting from objectives to the trial implementation requirements and timeline.

3.1 UC1 - Augmented tourism experience

The main goal of this use case is to provide the visitors of targeted museums with an improved and more engaging experience that relies on XR technologies to augment their visit and knowledge of touristic assets offered at each site. XR is the umbrella term that includes VR, AR, and Mixed Reality (MR). Even though these technologies are different from each other, they share some common goals that include the enhancement and the augmentation of the user experience with the introduction of digital objects such as: interactive 3-Dimensional (3D) models, binaural 3D audio, virtual avatars, and immersive (360 degrees) videos. The goal is to use of all these technologies in a seamless way in order to provide users with the best possible experience, according to each user's hardware, location, network capacity, and needs.

Over the next decade, a new era built on "digital interaction" that is based on "digital reality" will have a massive impact on human interaction behaviors as well as on every industry sector but mainly on the cultural and creative industry. In particular, XR is going to improve the tourism experience, and traditional means that give context to travelers will soon be replaced by such modern platforms that will be able to provide rich multimedia information on demand.

One of the most significant advances 5G-TOURS is its willingness to demonstrate on educational tourism, as the gamification of the exploring experience will develop new ways to make the visitors learn by playing and enhancing the interaction between humans and art. That is why UC1 Augmented Tourism Experience (ATE) is not only targeted to the visitors of selected museums, but is also aimed to attract and involve tourists/citizens/students nearby identified "Point of Interests" thanks to the development of engaging smart city services.

The concept of "immersive" experience requires the involvement of the user both indoors and outdoors, offering a set of services to the user, accompanying him from identified paths on the outside of the targeted museums to the most thrilling indoor experiences. Consequently, the purpose of those experiments is to enrich the cultural and touristic experience using technologies like immersive media content, intelligent video analysis and interaction with 3D art pieces deploying different and integrated involvement strategies, such as:

- smart guide to Museum
- gamification
- entertainment through Multi-faceted informative services
- blended Learning experiences
- access to smart city services for a better tourism experience.

The target users of this use case are general users from 6 to 99 years of age. The idea is that everyone can enjoy culture and tourism through technology enhanced paths, regardless of their level of digital literacy. That's why devices and equipment should be easy to use, possibly in each identified location and by anyone, youngster and aged, even with a strong inclusive approach towards disabilities (physical and cognitive).

Technology should not "disturb" the cultural experience, but instead accompany and enhance it, possibly without too many pieces of hardware, allowing a fast learning experience. Also, technology should not isolate individuals, but help organize and put in place community experiences, offering spaces for interactivity and real aggregation opportunities, through gamification and group of visitors/students' engagement.

To achieve these objectives there is a need to develop a properly equipped environments in the targeted museums that can be easily accessible by the general public and customized according to the demands (thus, not only professional target groups).

The use of most common devices like smartphones and tablets will be provided to allow an integrated, continuous and homogeneous experience for all both outdoors and indoors, with different levels and intensity from outside to indoor locations (e.g. museums, schools). 3D scans of selected objects, combined with new videos as well as existing contents will help offer a combination of high-quality content (broadcasting production) and AR contents. This will also be linked with UC4 and UC5. The possibility to offer existing contents (video, 3D models, photos) will be discussed, to promote further innovative crowdsourced augmented tourism experiences or innovative businesses.

Additionally, a smart city platform will be deployed to provide touristic information, leveraging on data about the environment and the number of people in different areas. Specifically, tourists will be provided with several smart city services, giving them information on (i) indoor (comfort) and outdoor (environmental) conditions, (ii) cultural/touristic interest, and (iii) tourist facilities provided by the city. To do so, the deployment will include indoor and outdoor sensors for monitoring environmental conditions (temperature, humidity, CO2, energy consumption, etc.) as well as beacons to provide information and interact with users on the aforementioned areas of interest. Smart city services will rely on several components typically involved in IoT scenarios. A platform, which will be deployed to support all the services made available to tourists, will be fed with data from sensors deployed in the trial areas, exploiting the 5G coverage available in those areas.

Finally, there is the intention to interconnect all XR experiences developed within the project into a unique, integrated touch point, which is going to be designed by the City of Turin in parallel. This touch point will be a web platform which will innovate the current website of the Torino museum where it will be possible to discover all the ongoing cultural/touristic offer with a dedicated space to show and promote technology enhanced cultural experiences. The platform as well as any XR experience will be designed to be mobile friendly.

The use case will be developed in the following two sub-trials:

- UC1.a Smart Guide to Museum - “In the very heart of Turin” (main location: Palazzo Madama)
- UC1.b Gamification - “Let’s play artist” (main locations: Modern art Gallery, Edulab)

3.1.1 UC1.a: In the very heart of Turin

The objective of this sub-UC is to create and test an integrated, immersive and personalized experience targeted both to the museum’s visitors and to tourists/citizens in the surroundings of the targeted point of Interests.

This will be made possible thanks to the deployment and testing of a virtual guide enabling interactive visits to targeted museums. These activities will be complemented through informative services provided both indoors as well as outdoors and provide an XR route for selected “City Walks”. Finally, smart city services related to communication of environmental data will be provided, thanks to dedicated indoor and outdoor sensor networks, to be deployed in the surroundings of targeted museums.

Virtual Guide and Interactive Visit into the targeted museum

The idea is to offer an assisted visit with mixed reality content to tell the history of the targeted museum, its architectural stratifications or its uses as well as its main collections. Indeed, museum managers involved into the use case design in Turin report that museum visitors ask to know more about how the building was lived across ages and the history which was made inside very often.

This is particularly true for Palazzo Madama, due to its 2000 years of history and being survived through time. The museum has the historical sources (documents, engravings, paintings, some photos) that can be shown through a device while the user is visiting the museum to counterpoint the narration of the historical figures selected to represent Palazzo Madama and its history. The idea is to combine a multiple experience from outside to inside. Specifically:

- from the external point of view, the objective is to show how the building was, in specific periods of time, applying an exterior layer building upon existing studies and graphics
- internally, the idea is to convey a view of the rooms that belonged to the second *Madama Reale* to visitors, as they were in past centuries. Moreover, starting from a furniture object which can be modeled, the possibility to showcase its use in the past and eventually its creation process will also be provided. Considering that a strong storytelling reinforce technology can significantly enhance experiences, all this should be complemented by more emotional functionalities (through holograms, videos or avatars)

representing the second Madama Reale, telling the user the history of the Palazzo and museum from their point of view.

This emotional learning path through the virtual guide will be context-aware, adapting to the characteristics of the visitor (language, age, etc.) and understanding their indications and commands. It will provide information such as details of the piece of art the visitor is looking at or the history of the place the visitor is in across ages. Rooms or pieces of art, seen through XR will be shown in 3D, allowing users, using their own devices to manipulate 3D objects, such as rotating them freely. It will also allow users to access additional information about masterpieces inside the museum, their creation, other works of the same artist and artistic movement details, the taste of life of the targeted age, etc. Furthermore, the virtual guide will be location-aware, empowered by beacons, providing information such as the location of the visitors.

Informative services and Extended Reality path for selected "City Walks"

An additional service provided to tourists/citizens will be the organization of "Extended Reality path" across different cultural/tourist points of interest in Turin, leveraging existing contents, experiences and technologies, to scale and improve the engagement of tourists/citizens/students to immersive cultural activities inside the cities and from place to place. This will entail the identification of existing contents and the need of new ones as well as the design of integrated indoor and outdoor experiences enabled by the same usable devices mentioned above. Moreover, the idea is to also put both the current and the new offers of technology enhanced experiences into a network and link them with existing cultural path.

Among the existing experiences, it is worth mentioning the following ones:

- Museo Pietro Micca – Galleries
- Museo del Risorgimento – Hall of the "Subalpine Parliament"
- Museum of Oriental Arts (MAO)
- Palazzo Madama (a first test bed was realized in the context of 5G-MoNArch project [10])
- MAUA – Turin Museum of Augmented Urban Arts
- Innovation Miles Extended Reality Path, to be developed within the 5G-EVE project.

Generally, the proposal is to renovate current cultural/touristic path through a new way to visit and live the city as a citizen, student or tourist. Some cultural/touristic paths, to be identified during the operational design phase, will then be redesigned, and put into an existing network (and eventually re-adapted), XR experiences with new ones. This new offer of technology enhanced path will be publicized and made accessible through the Torino Musei Portal, which will be renovated by the city of Turin accordingly.

In order to further engage the start-up community around novel 5G enabled services, the development of new contents could include the organization of hackathons/jams (e.g. design sprint-like event in which programmers and other domain experts, collaborate intensively on software projects) for the production of interactive experiences and games.

Smart city services, thanks to dedicated indoor and outdoor sensor

The overall use case does not only take into consideration indoor touristic places, such as museums, but it also aims at providing an improved and more informed tourist experience even in outdoor spaces, such as squares, monuments and streets. In this sense, a series of smart city services will be implemented to support users in their "cultural walk experience" around the city, helping them to discover the most relevant places and artworks "in the very heart of the city" which match with their preferences.

A dedicated mobile application will be provided to users to interact with smart city services, allowing them to obtain touristic information (e.g. audio guides, multimedia content), while getting information about city logistics (transport, opening times and crowding of places) and safety (pollution, solar radiation, critical events) at the same time. To this aim, users will be characterized according to their physical location (e.g. indoor or outdoor position) and preferences in order to guarantee them the most tailor-made visits. Smart city services will be based on different types of information, which may be either Open-Data (provided by the Municipality), or information obtained from sensors that will be deployed in the area covered by the trial.

In this sense, Piazza Castello and its surroundings will be equipped with beacons, to provide integrated information about cultural offer and other public/institutional contents (e.g. traffic, events, etc.) and environmental sensors (pollution, weather, etc.). Finally, Wi-Fi scanners will be installed to gather and analyse data about tourists' preferences and help the Municipality to best plan concerned local policies (cultural offer, traffic management, safety and security).

3.1.1.1 Application Components

As already mentioned in the 5G-TOURS deliverable D2.1 "Use cases, deployment and techno-economic requirements - high level description" [6], the UC1.a will include the following features:

- consumption of multimedia contents such as: 3D objects, audios, texts, videos (immersive) etc. through a customized and adapted XR interaction,
- interaction (zoom, rotate, exploit, etc.) with 3D objects (art artefacts) met during the visit,
- access to multimodal (immersive) media contents such as: customized audio guides, written guides or detailed description of art pieces that are observed during the visit in the user's preferred language,
- interaction with virtual avatars to offer personalized itineraries based on the user's preferences and how crowded the rooms in the museum are,
- temporarily save multimedia contents offered by the museum to be played after the visit or to be shared with family or friends, making sure that any digital rights management requirements relating to the content are respected.

Application components for Extended Reality

The UC1.a describes a virtual guide service to deliver a hyper-personalized and interactive experience relying XR technologies to the museum's visitors. The virtual guide is expected to be context-aware, and thus the software will adapt the system to the characteristics (culture, language, etc.) of visitors to enable a proper interaction and understanding of the user's indications and commands.

The software will provide basic information such as details of the piece of art the visitor is looking at; or, if the statue is broken the users will be able see how it used to look like when it was new. Art pieces will be seen through XR in 3D, allowing tourists to interact with them (e.g. rotate them freely) and providing extra information about their creation, other works of the same artist and artistic movement details, etc. Moreover, the virtual guide software will be location-aware, empowered by physical web beacons installed in the museum, in order to provide contextualized information.

In terms of software architecture, the XR application will follow a classic client/server architecture (Figure 14). One or more server hosts will deliver and manage most of media resources and services to be consumed by the end user. End users' devices (smartphones, tablets, smart glasses, etc.) will be remotely connected to servers over a 5G network.

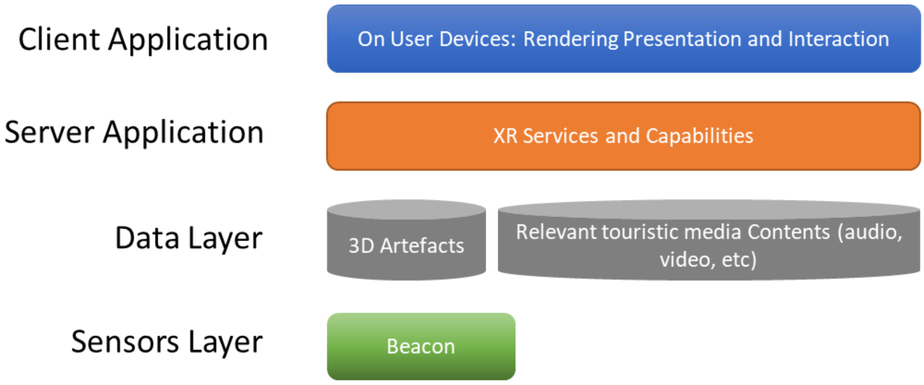

Figure 14 – XR application software architecture

Application components for smart city services

As mentioned above, end users will be able to access smart city services that are built on the basis of information that comes from different sources, such as field devices (e.g. sensors), users' smartphones or open-data platforms supplied by the municipality. Figure 15 shows the main functional blocks that will be involved in the implementation of the use case.

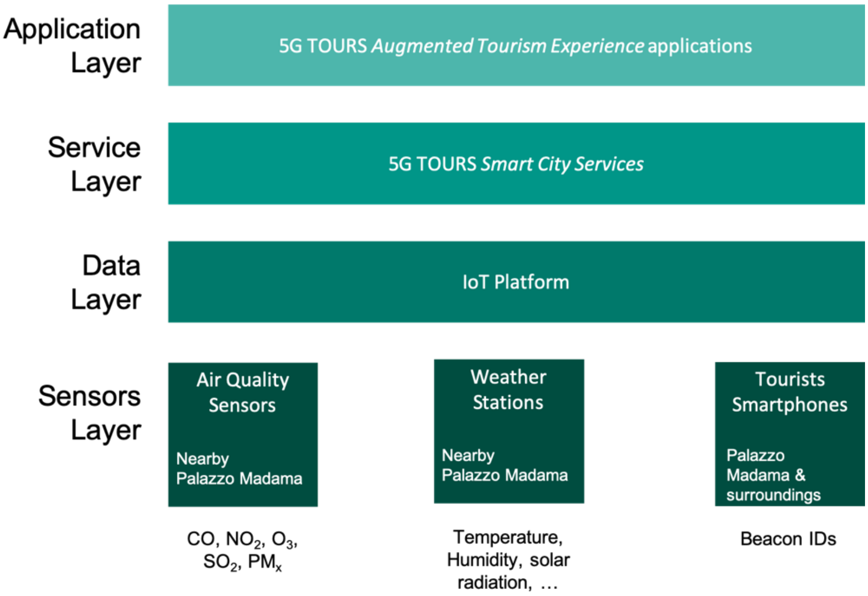

Figure 15 – Smart City services architecture

Data from information sources (Sensor Layer) is sent to a storage and forward to an IoT platform (Data Layer). Developers can access the collected data through the open Application Programming Interfaces (APIs) of the IoT platform, and then aggregate and process the information in order to create value-added services (Service Layer) that, in turn, can be used by end-user applications (Application Layer) through open APIs.

In the context of UC1.a, the information obtained from field devices (e.g. beacons, sensors) will be elaborated and provided to tourists through web / mobile applications (even developed by third parties) that will be mainly accessible through their personal devices (smartphones, tablets), as well as through large displays placed in the focal areas. In particular, users will be able to make full use of the services provided by the smart city services to obtain tourist information and all the facilities offered by the city. The applications will be context-aware, allowing users to live a personalized tourist experience based on their preferences and expectations, such as:

- get personalized itineraries based on cultural preferences and tourists' needs (e.g. time available, willingness to walk, etc.),
- consult environment and pollution information and get suggestions about touristic walking routes selected based on the best air quality,
- exploit information regarding the crowding of touristic places (e.g. museum rooms, squares) in order to allow the tourist to better plan his visit experience.

3.1.1.2 Trial description

As already mentioned, Palazzo Madama is a huge building developed during several ages, with "different" stories to be evoked. It now hosts different pieces of arts, sometimes delicate to treat or difficult to be digitalized. Main critical points to be taken into account to define the trial are the following:

- It is impossible to showcase and tell the history of all the building stratifications across the years, considering the available financial resources, existing contents and project timeline.
- Some of the pieces of art/materials conserved inside the museums, such as the ceramics preserved in glass cases, can hardly become digitized objects, due to problems related to reflection.

- The building is made up of different floors with spaces organized differently and some dedicated to permanent exhibitions.

Therefore, in order to overcome this variety of conditions, the idea is to identify a single testing area and focus only in one historical age for the overall storytelling. Due to all these considerations, the trial activities for XR will be carried out at the first floor of Palazzo Madama, where some of the pictorial and wall decorations from the Baroque period are retained (see Annex A). The XR experience will also include the external part of the building. The target age will be the seventeenth century (1700) due to the existing work present within, and the graphics already developed by the museum itself.

The focus of the storytelling and the complete set of application components will be the object of further study activities within the operational design phase. In terms of available contents for the realization of XR experiences, Fondazione Torino Musei owns a photographic documentation, maps, embossed drawings, and videos of 2018/2019 exhibitions (from which it is possible to extrapolate panoramas of some target environments), and reproductions of historical engravings documenting the different stages of construction of the Palazzo Madama from the outside. All this material is also available as digital scans. However, no 3D models are available, therefore new contents will be developed. Production of contents will also be linked with UC5 activities and carried out as follow:

- For the creation of (static) 3D models to be used for the touristic city use cases, through skill and devices (like 3D scanners)
- For the creation of 4K-HDR audio video content to be used for video distribution tests, as well as dissemination activities, thanks to the Turin's TV Production Center RAI for the technical and artistic part.

In the next two sections the devices used in this use case are described.

XR experience

In terms of hardware equipment, the idea is to develop experiences for different target users such as i) "pop-experience" for the general public through mobile phone or tablets and ii) professional targeted experiences for specific users (e.g. architects, students).

To display the XR experiences, special hardware needs to be used. The technology that is being listed is comprised by devices that have 5G antennas and can effectively be used as immersive displays. To better target each use case, we will specify the hardware configuration for VR experiences and the configuration for AR experiences.

For the experiences of this use case that require VR, we will be using handset/mobile based solutions since these provide both support for 5G connectivity and a compatible headset to experience the immersive applications. The devices used will be the *Samsung Galaxy S10 5G* coupled with Samsung Gear VR or Google DayDreams (Figure 16).

Figure 16 – Virtual Reality devices

For reference, the models of the hardware devices area SM-G977B (phone) and SM-R325 (headset). These devices have compatibility with 3 degrees of freedom VR experiences. For information about compatibility among devices, see [11].

Experiences that require AR will be dependent on the mobile device itself. The S10 5G devices can be reused for these scenarios, and thus, smartphone AR (Figure 17) is preferred. The cost of other devices like AR headsets (i.e. Hololens 1 & 2 or MagicLeap One) coupled with their enterprise focus, complex development environments and inability to easily make the experiences available from the online portal are deterrents as alternatives.

Figure 17 – **A device showing an AR application. Image used as reference of AR on a mobile device.**

For the use cases where 360° videos are required, Gear 360° (Figure 18) or 360° RICOH THETA (Figure 19) cameras will be available. These assets can be used for backgrounds, context or multimedia content inside the XR experiences.

Figure 18 – **Gear 360 camera**

Figure 19 – **360 RICOH THETA**

These devices allow for three degrees of freedom immersive experiences. This means that there is no position tracking for the experiences themselves. This does not mean however that there will be no support for high end 6 degrees of freedom (rotation and location tracking) immersive experiences. The choice of development platform allows to progressively enhance the experience into high end desktop machines. The choice of devices provides untethered advantages and can scale to be used by devices of people around and outside the designated testing devices, which in itself permits unprecedented reach and scalability.

Newer and upgraded devices that might come out before the acquisition of all the required hardware, can be analysed to bring the upgraded versions into the mix, since improvements in the usability or ergonomics of such devices might be present. Furthermore, in order to provide different experience and test different technologies even towards different groups of users (e.g. more professional ones or within "Edulab") the use of holographic devices (Hololens, Magic Leap, etc.) will also be addressed. A demo in the context of UC4 and UC1 addressing the application of holographic devices and the porting of content over this type of device will be carried out.

Development of indoor and outdoor informative services

End users will be given the opportunity to interact with various services provided by the museum and the city through a mobile application. The provision of these services requires an appropriate setup of the areas (indoor and outdoor) in which the trial will take place, which involves the installation of field devices. Visitors will be provided with a mobile application to be installed on their personal smartphones, allowing them to access a plethora of services provided by both the museum and the city.

In particular, short-range signaling devices such as beacons (Figure 20), will be placed inside the museum rooms to allow indoor localization of visitors through their smartphone and to deliver detailed information about the artworks close to them. It will also be possible to calculate the number of people in a given room at a given time. This information will permit the museum to recommend "smart itineraries" to visitors, according to the current crowding of the rooms. The same contents will be also be displayed in some physical information points (e.g. displays) which will be installed in one or more focal points, in order to create a unique access point to the digitally enhanced Turin cultural offer.

Figure 20 – Beacons

In addition to those inside the museum, the following additional devices will be installed in the surroundings of Piazza Castello:

- WiFi scanners or beacons will be placed in museum rooms or close to outdoor touristic points of interest (e.g. squares). These devices allow the detection of WiFi and Bluetooth devices in close proximity in order to estimate the crowding of a place.
- At least one weather station (Figure 21) will be installed outdoors, to monitor the weather conditions such as ambient temperature and humidity, atmospheric pressure, precipitation, wind speed and direction.

Figure 21 – Weather station

- At least two air quality sensors will be installed to obtain precise information about the current pollution and how it evolves during the days. The device which is going to be adopted is Libelium Smart Environment PRO, which enables the Air Quality Index (AQI) calculation, thanks to 16 gas sensors that provided extremely accurate ppm values and a high-end particle matter sensor. In particular, sensors that will be used are for: CO, NO_2, SO_2, O_3, PM_1, $PM_{2.5}$ and PM_{10}.

  The device must be installed outdoor and requires a 5V supply. Its size is about 30cm x 30cm x 20cm.

Figure 22 – Air Quality sensor

Table 2 contains the main activities planned for UC1.a:

Phases	Description
Phase 1: Site inspection	Definition of the location, site visit, check of the environment to identify areas and on-site 3D objects (to be modeled). Localize where beacons and sensors will be installed.
Phase 2: Requirements Gathering and Architecture Design	Fine grained (technical) requirements gathering process and low level design of the overall architecture.
Phase 3: Implementation (three milestones)	The solution implementation will follow an agile process. Many versions of the solution will be released. However, the solution implementation itself will follow three key milestones.
Phase 4: Two laboratory tests	Part of a routine checkup to look for bugs and malfunction in the solution. This may involve key and selected general users with the help of TOR.
Phase 5: Solution deployment and Operation to run the trial	The solution is deployed in TOR and operated. At this stage the solution is ready to be used by general users.
Phase 6: Trial with Release candidate	General users can access the contents
Phase 7: Experiment and Assessment preparation	Animation activities targeted to students and start-up communities to stimulate the market of 5G enabled XR/gamification solutions, including the organization of "Jams/hackathons" and/or the launch of "Call for testing" within Torino City Lab" Initiative. Organization of communication campaigns in targeted Museums and/or city wide.
Phase 8: Experiment Assessment and final Evaluation	The data generated by the trial is assessed so there is the overall assessment of the Experiment (also of the technologies involved in it).

Table 2 – UC1.a Phase of the Trial

3.1.2 UC1.b: GAM and Edulab – Gamification, let's play artist

This case study will focus on the contemporary section of the collection of GAM, to convey the importance of the artistic gesture in contemporary art through a process of gamification. Indeed, for many artists, from abstract expression on, the painted canvas is not an artwork per se, but a result of the performative action that has generated it. The objective of this sub-use case is to allow the user to enter into the life of a selected artist, understand it and eventually test the art creation process as well as learn about it through gamification.

The targeted visitors are mainly students, families with children or small groups of families with children. The experience to be developed will mix XR with gamification and will take advantage of innovative video contents produced within UC4.

The user will be introduced to the experience of entering into the life of the artist through an emotional/engaging short video and/or though holograms/projections. The setting could include the artist hologram moving into the space to tell his story accompanied by music. Additionally, a video of approximately 5 minutes duration could be displayed. This will allow to enjoy the gamification experience, whose main objective could be linked to:

- allowing the target user to enter into the life of the artist, displaying his studio and putting its materials at disposal
- creating an art piece, reproducing the artistic gesture.

Tourist/student will be invited to enter into the artist studio and try his material. They could try to collectively paint a virtual canvas to understand the importance of the artist gesture via a first-hand experience. Gamification technologies will be used to maximize end user's engagement and participation as well as to make the learning experience more amusing. To this end, this sub-UC will evaluate for instance the following experiences and related equipment:

- virtual canvas,

- solutions able to convey the gesture of the creation of a piece of art based on the ones that are currently at the museum,
- clues placed around the museum with different tests related to the pieces of art, encouraging the visitors to learn about them to advance in the game,
- minigame set-up starting in front of an art piece, asking the visitor questions adapted to his age and giving different educational brief content depending on the answer.

All these solutions should promote collaborative/group activities eventually enjoyable in telepresence and thus stimulate distance/cross collaboration between different places (e.g. from GAM to Edulab or other locations to be identified, like hospitals or airports). Some of the aforementioned solutions could be adapted for educational purposes and realized at Edulab, where the idea is to setup a dedicated laboratory to offer learning through gaming experiences to students using more professional equipment such as Hololens. Besides that, this use case should be interlinked with UC2, allowing collaborative gaming experiences between GAM and Edulab, thanks to telepresence functionalities.

3.1.2.1 Application Component

Application components for Extended Reality &gamification

The UC1.b relies on a gaming and gamification approach to maximize the end-user's engagement and participation as well as to make the learning experience more amusing. Therefore, the solution includes game-based learning and gamification features that are accessed by interactive technologies such as AR or VR. In depth the solution will provide:

- a multiplayer interactive game about a virtual canvas that visitors can collaboratively paint, inspired by the museums' art pieces, creating an integrated huge piece of art made by lots of visitors,
- a mystery game at the museum where visitors search clues which are placed around the museum with different tests related to the pieces of art, encouraging visitors to learn more about them to advance in the game,
- a virtual 3D puzzle of a 3D piece of art game (such as tables or chairs[2])
- the creation of a piece of art based on the ones that are currently at the museum, using a canvas with the background of a painting or a virtual block of stone for sculpting
- an emotional introductory video to be developed in collaboration with RAI.

In terms of software architecture, the solution will follow a classic multiplayer game server architecture. Figure 23 shows a simplified multiplayer game server architecture that is not showing the typical industry strength deployment with a load balancer and a separate identity management capabilities for better clarity. However, the architecture shown here is functional, so it is still capable of serving hundreds of concurrent players.

[2] https://www.palazzomadamatorino.it/en/node/16221

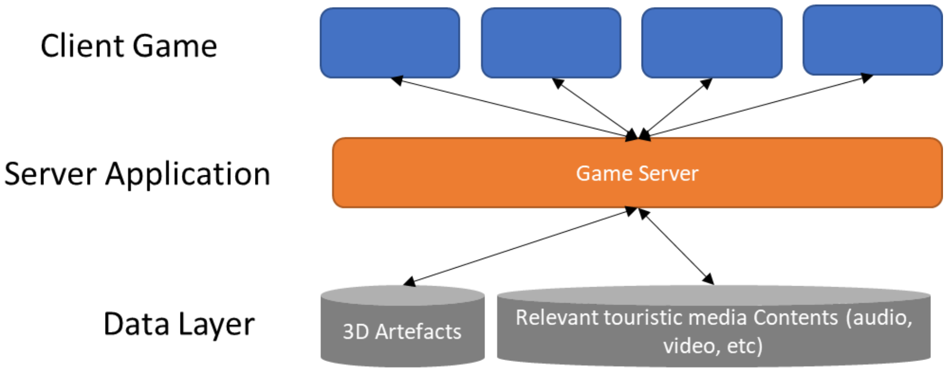

Figure 23 – Multiplayer game server architecture

In the client-server model above shown, a 5G connectivity allows data communication among all clients to the game server. The server is accessible by all the players' devices and has a significantly high bandwidth allocation and low-latency to serve hundreds of contemporary requests in order to maximize the quality of experience (QoE). The advantage of this model is the accessibility of the game server by all users that are connected to the internet. Moreover, to avoid the game server bottleneck the architecture can be improved by adding a load balancing capability.

In the configuration shown above, the load balancer service centralizes all the user interaction the game server, making it the first contact point for all users trying to log in and interact with the server, leaving the load balancer to only respond to the clients with the URL of the least loaded server. Finally, this model seems to be less performant, but much more secure with respect to a peer-to-peer (P2P) approach where clients create a direct communication connection among the players' devices.

3.1.2.2 Trial Description

The trail of this sub-UC will be executed at GAM and Edulab. The GAM trail presents some challenges that must be taken into account. First, the objective is to offer the possibility to have a creative experience, valorizing the "gesture" and not substituting it. Second, the collections are not permanent due to several changes and loans to other national and international institutions and this imply that it is better to focus not onto a single collection but to target laboratory activities either for schools or for families or adults. Edulab connected trial will be carried out into a dedicated space called "Art, Cinema and Theatre laboratory.

The trials detailed description follows:

Trial at GAM

In this use case, the visitors will be in an immersive room where the virtual canvas, inspired by the artwork of Nicola De Maria, should be on each wall of a small room. The artist creates immersive environments with his painting using very simple and colorful shapes (flowers, stars, etc.) that are often combined to create new forms (Figure 24, Figure 25 and Figure 26).

Figure 24 – Nicola De Maria's piece in the collection of the GAM.

Figure 25 – Some examples of De Maria's immersive room.

Figure 26 – De Maria's shapes.

The immersive room will give the visitors the impression that they are in a De Maria's artwork, but they will be able to interact with it, changing the colors, moving the shapes around in the room (being very simple shape, they should be not too difficult to model), paint their own shapes or recombining De Maria's into new ones. This action will be both amusing and essential to understand the poetics of the artist. The immersive room will provide the museum with an instrument that can be used independently by visitors. Nicola De Maria's artworks, with their large and very colorful images, will invite the public to perform playful and creative actions. More information about the trial provisional setting are provided in Annex A. Experiences at GAM will be made possible through mobile devices, so to be best adapted to any users.

Trial at Edulab - Art, Cinema and Theatre laboratory

Experiences at Edulab will be conveyed through more professional devices, such as hololens/visors which will be purchased by the city of Turin and possibly complemented by RAI. At Edulab, the activities will be offered within the school year from September to June. In both testing areas, the trial will last 24 months, during year 2 and 3 of 5G-TOURS and they will possibly be kept operational after the project completion (sustainability after project will be studied).

Development of experience

Similarly to UC1.a, the end users involved in these experiments will be given the opportunity, to consume the gaming experience through a mobile application to interact with the various games provided by the museum. To display the XR experiences, the Samsung Galaxy S10 5G coupled with Samsung Gear VR or Google Day-Dreams (Figure 16) will be used as in UC1.a.

Table 3 contains the main activities planned for UC1.b:

Phases	Description
Phase 1: Site inspection	Definition of the location, site visit, check of the environment to identify areas and on-site 3D objects (to be modeled). Localize where beacons and sensors will be installed.
Phase 2: Requirements Gathering and Architecture Design	Fine grained (technical) requirements gathering process and low level design of the overall architecture.
Phase 3: Implementation (three milestones)	The solution implementation will follow an agile process. Many versions of the solution will be released. However, the solution implementation itself will follow three key milestones.
Phase 4: Two laboratory tests	Part of a routine checkup to look for bugs and malfunction in the solution. This may involve key and selected general users with the help of TOR.
Phase 5: Solution deployment and Operation to run the trial	The solution is deployed in TOR and operated. At this stage the solution is ready to be used by general users.
Phase 6: Trial with Release candidate	General users can access the contents
Phase 7: Experiment and Assessment preparation	Animation activities targeted to students and start-up communities to stimulate the market of 5G enabled XR/gamification solutions, including the organization of “Jams/hackathons” and/or the launch of “Call for testing” within Torino City Lab” Initiative. Organization of communication campaigns in targeted Museums and/or city wide.
Phase 8: Experiment Assessment and final Evaluation	The data generated by the trial is assessed so there is the overall assessment of the Experiment (also of the technologies involved in it).

Table 3 – UC1.b Phase of the Trial

3.2 UC2 - Telepresence

The main goal of this use case is to provide the possibility of a robot located inside a museum to be controlled by a remote user by leveraging an underlying 5G network capable of meeting the strict Key Performance Indicators (KPIs) needed for the effective control of the robot. Museums are responsible for reaching out to expose their educational resources, and create meaningful and engaging experiences for, as many people as possible. Telepresence robots have the potential to authentically extend access to historically excluded audiences such as disabled people, social disadvantaged people (e.g. substituting or complementing school field trips), people outside the country (in a way to attract tourists/users), providing enhanced education activities at schools (without moving from their own classroom) as well as offering niche experiences to a wider audience for a longer time. The most prominent applications of this teleoperation use case are a visit to the museum by a visitor located at a remote station (school, home, hospital, etc.) or the surveillance of the museum by an operator external to the museum.

The remote operator or user will be able to teleoperate the robot inside the museum by using a dedicated laptop and joypad. Images from the robot will be sent to the remote-control station where the user or the operator is located. Additional monitors could be used in the same or in a remote location to display the content to other groups of users.

The communication needs to be bi-directional: commands to control the wheels of the robot will be sent from the remote-control station to the robot, and the robot will provide feedback including images of its visual field and other type of signals, such as signals to the user to notify the presence of obstacles in the path. 5G will be used to stream images from the cameras on-board the robot to the remote console, as well as to transmit the control signals from the headset and hand trackers to the robot. As a result, this use case will benchmark the bandwidth and latency provided by the 5G network for robotic applications.

The use case will be developed by the following three trials:

- UC2.a Palazzo Madama exclusive exhibitions for all

- UC2.b Play and visit modern art from museum to school
- UC2.c Surveillance of the museum

3.2.1 UC2.a: Palazzo Madama exclusive exhibitions for all

The idea is to enlarge the public for selected exhibitions in order to make these experiences more accessible to all and for a longer period and/or to use these exhibitions to attract foreign visitors/tourists. The selected location for this sub use case is the Palazzo Madama, where exhibitions are cured by highly specialized professionals, that often live outside the city or abroad. These professionals can give tours of the exhibition during the opening days to very few people. Using telepresence robot, there will be the possibility to arrange 2 to 3 curator led visits to the temporary exhibitions or to the permanent collections, allowing more people to benefit from their expertise.

The target audience of this use case includes interested visitors from Turin or abroad, who cannot directly join the museum. A strong focus is towards disadvantaged groups, that could have difficulties joining the exhibitions in real life (disabled, people in hospitals, elderly in retirement homes, marginalized communities, etc.). Indeed, telepresence enabled by 5G can act as assistive technology, allowing people with physical or cognitive disabilities to enjoy visits and experiences and open the cultural offer for all. Additionally, the idea is to use telepresence to attract tourists from outside Piedmont and thus offer a "taste" of Turin through robot-led experiences. This means that target involvement strategies will be identified to accompany these experiences to adapt to different conditions (mental vs physical disabilities), languages and final objectives (involvement vs attraction of tourists). Further locations could be identified in the operational design phase integrating and complementing activities carried out with UC1. The possibility to study and develop interworking opportunities with the other 5G-TOURS nodes in Rennes and Athens, will be considered.

3.2.1.1 Application Components

In the context of the UC2a Exclusive exhibition for all, a telepresence robot control application will be implemented. The UC will rely on a telepresence robot to extend the possibility to remotely enjoy a museum visit for a wide range of people.

The solution needs a control room application used by the operator (or skilled user) to drive the robot remotely, looking at the environment using the camera the robot is equipped with, and the telemetry information provided by the robot. Control command and telemetry of the robots are provided by cloud robotics infrastructure. Live videos from robots will also be used to provide end user with a remote experience using low latency streaming projected on a wide screen.

As shown in Figure 27, at the low level, the robot control application interacts with the robot, handling the registration and robot authentication operation, API and wireless channel adaptation. Furthermore, an application layer will manage fleet control operations, and other middleware level operations. Finally, the user interaction layer will provide two user Interfaces (UIs) for the operator control room and the remote visit room equipment. Depending on the UC scenario, the operator control room and the remote visit room can be either co-located or not.

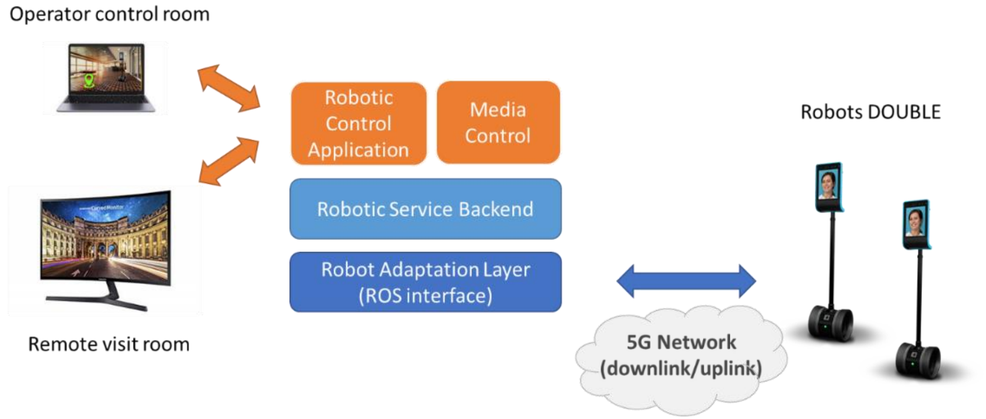

Figure 27 – UC2a Cloud Robotics Infrastructure application architecture.

3.2.1.2 Trial description

The trail activity of this use case needs to be planned taking into account the following main points:

- planning activities of the targeted exhibition (milestone),
- development and adaptation of the telepresence platform,
- development of interaction pattern and equipment of the remote station.

The identification and planning of the targeted exhibition are a crucial step in the trial organization. Indeed, this will lead the museum managers to include the exhibition curator from the beginning in order to develop a two-fold strategy for an engaging exhibition towards people in presence and remote. Considering different needs, a link to disadvantaged and/or disabled groups may also need the support from professionals (e.g. psychologists) for identifying the right involved communication tools and language.

In terms of technical feasibility, the first step will require a site inspection to identify the locations where the robot can safely move around as well as the locations for the control and remote visit rooms where the control equipment's will be installed. From this perspective, significant attention must be paid during the deployment of the control and remote visitor rooms, in order to provide the best user experience while respecting safety and security regulations inside the museum buildings. Next step will define the remote-control application UI and features, to allow the specification of application backend and other software components.

During the development phase, the robot API will be integrated, using the abstraction layer Robot Operating System (ROS) compliant provided by the robot manufacturer. At present time Double Robotics provides two different telepresence robots[3] : Double 2 and Double 3. It is planned to make use of the Double 3 robot since it provides more advanced features with respect to the Double 2 model. Since continuous improvements are available in robot features, new versions of hardware parts or firmware of the robots can be analyzed during the trial to evaluate the gains in terms of use experience if integrated. At the time of writing, the Double 3 robot (see Figure 28) provides the following main features:

Self-Driving

An array of 3D sensors enables Double 3 to understand its environment, where it's safe to drive, and how to divert around obstacles to reach its destination. Built-in obstacle avoidance means that completely untrained drivers can drive Double 3 without bumping into walls or people.

Click-to-Drive

Click-to-Drive allows a user to simply click anywhere on the floor and Double will drive there, avoiding obstacles along the way. The camera view is enhanced with virtual 3D objects that highlight drivable areas, obstacles, and important places such as charging dock. This type of enhanced view is commonly referred to as Mixed Reality (MR). MR is like AR, except virtual 3D objects are added into the live video stream.

Unified Pan-Tilt-Zoom

Two 13 megapixel cameras provide an ultra-wide field of view and multiple levels of zoom. A new precision gear-motor enables both cameras to physically tilt up and down. An advanced software algorithm combines all of the movements into a single and seamless user experience.

Six Beamforming Microphones

An advanced array of six microphones helps the driver hear people from far away and with less background noise. The integrated audio system enables full-duplex audio (two-way simultaneous audio) to be more robust in challenging environments.

[3] www.doublerobotics.com

Developer Friendly

A developer API enables customized applications to be built in Double. Modular subsystems allow developers to choose the features they need for their application. The tiered architecture provides hooks to sensor data and autonomous features at various levels. Various expansion ports and mounting points allow additional hardware to be added.

It should be highlighted that not all the robot's features could be exploited in the deployment of the use case. Further analysis on this aspect will be conducted during the design phase.

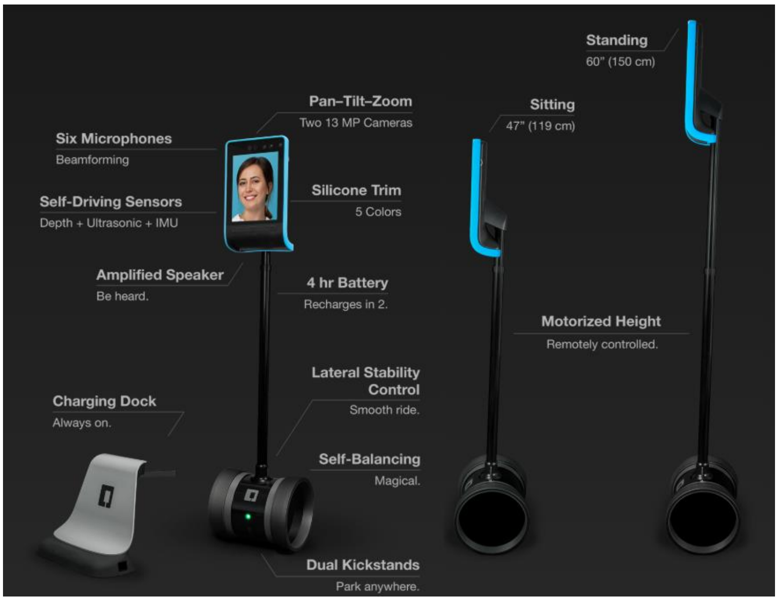

Figure 28 – Double 3 robot features

Table 4 contains the main activities planned for UC2.a:

Phases & timeline	Description
Phase 1: Site inspection	Definitions of the location, site visit, check of the environment to identify areas where the robot can move safely. Check for potential barriers, localization issues and preliminary evaluation about the need beacons installation.
Phase 2: Remote control application specification	Application and backend specification
Phase 3: Remote control application development and robot integration	Application and backend development, robot API integration
Phase 4: Deployment and Test of the network	Integration of the solution with radio connectivity, validation in laboratory environment at TIM.
Phase 5: Deployment of control room and robot	Setup and deployment of robot and control room in museum building, preliminary test
Phase 6: Beta Test of application	Test with the robot in TOR with 4G / 5G
Phase 7: Test of application in real condition	Test with the robot in TOR with 5G
Phase 8: Monitoring and Evaluation	Evaluation of results from phase 7, improvement of the application, preparation of the final test

Table 4 – UC2.a Phase of the Trial

3.2.2 UC2.b: Play and visit modern art from Museum to School

The objective of this sub-UC is to offer enhanced educational activities to students at school, to be integrated in their school programs. The target audience for this application is schools/families with children from 6 to 13 years of age. The selected location for this sub use case will link students located at the Edulab premised with GAM, allowing them to enjoy an educational and gamification experience around modern art remotely.

Integrating UC1 and UC2, will allow to test innovative learning experiences in the STEAM, blending remote visits to the Modern Art Gallery, as well as practical activities linked to a dedicated “Treasure Hunt”. Gamification is seen as a promising tool for learning and the idea is to build an interactive game, which could put different teams in competition (in presence and remotely) where people at Edulab can solve quizzers and/or search for clues to solve a “mystery” about the life and work of a selected artist.

This UC will be developed in coordination with UC1.b and will target the same artist, Nicola De Maria. Through remote visit people at school will have access to the dedicated exhibitions paths as well as to some of the virtual experiences developed within the dedicated immersive room onsite. These activities could be linked to a dedicated educational module to be offered to several schools in Turin and deployed in the “Art, Cinema and Theatre” laboratory within the Edulab. Accompanying activities will be provided by learning professionals at Edulab to complement this technology enhanced experience.

3.2.2.1 Application Components

The application components for UC2.b are the same as the ones described for the UC2.a. For the gaming experience component, an underlying telepresence robot control application and media functionality will be used to involve the users in a more interactive experience. In the UC2.b bidirectional media flow will be used to allow remote users to better interact with the control operator and other people inside the museum area.

3.2.2.2 Trial description

The trial steps will be quite similar to those described for the UC2.a. Here the main focus is to allow interaction within targeted visits/laboratories within GAM and Edulab or other places to be identified. In addition to that, it is important to draw a proper storyline to involve the users.

More professional equipment could be used and deployed at Edulab, in line with UC2.a like hololens or similar.

Table 5 contains the main activities planned for UC2.b:

Phases & timeline	Description
Phase 1: Site inspection	Definition of the location, site visit, check of the environment to identify areas where the robot can move safely. Check for potential barriers, localization issues and preliminary evaluation about the need beacons installation.
Phase 2: Remote control application specification	Application and backend specification
Phase 3: Remote control application development and robot integration	Application and backend development, robot API integration
Phase 4: Deployment and Test of the network	Integration of the solution with radio connectivity, validation in laboratory environment at TIM.
Phase 5: Deployment of control room and robot	Setup and deployment of robot and control room in museum building, preliminary test
Phase 6: Beta Test of application	Test with the robot in TOR with 4G / 5G
Phase 7: Test of application in real condition	Test with the robot in TOR with 5G
Phase 8: Monitoring and Evaluation	Evaluation of results from phase 7, improvement of the application, preparation of the final test

Table 5– UC2.b Phase of the Trial

3.2.3 UC2.c: Surveillance of the museum

This use case will contribute to tele-surveillance functionalities of the same robots deployed for the telepresence remote visits to showcase the mix used of these technologies enabled by 5G and responds to the different needs of museums by day and by night.

In the surveillance use case, the robots are controlled remotely by a security operator in a local or in a remote control room. The museum surveillance can take place both during day and night hours, according to the features of the robots that will be used.

The idea is to test tele-surveillance for a number of museums (at least 2) in order to verify how tele-surveillance through robots can improve – and not substitute – security professionals, offering improved tools to carry out their work in a safer way. The selected test beds will be both Palazzo Madama and GAM. The target users in this case include the building managers and security professionals. Indirectly, this use case also affects the final users who will have the opportunity to enjoy their visits with improved safety and security conditions.

Data produced in UC1 thorough sensor networks (including wi-fi scanners) about environmental/safety conditions as well as the presence/concentration of people indoors and outdoors, will be integrated into this use case, with the aim to figure out how 5G enabled service scan can support building managers/museum directors to improve their facility management activities.

This surveillance use case includes the usage of the following systems and devices:

- The Double 2 or Double 3 robot by Double Robotics,
- The R1 humanoid robot provided by IIT [12],
- A network of distributed sensors for the detection of critical events.

3.2.3.1 Application Components

Remote surveillance

For remote surveillance during the day, the application components for UC2.c are the same as the ones described in UC2.a. The remote surveillance operator can use the robot control application to move the robot and supervise the visitors inside the museum or in locations that are forbidden to the public.

For remote surveillance during the night, R1 is an advanced humanoid robot, equipped not only with cameras and microphones, but also with arms and hands, which can be used to grasp and manipulate objects (Figure 29). Similarly, to Double 2, in this use case R1 will be tele-operated by an experienced user who will control robot movements from a remote control room and will receive the images from the robot cameras. Additionally, the surveillance task will be enriched by an object detection and recognition application that will inform the sentry if something suspicious is detected in the scene. The main components of this application are shown in Figure 30.

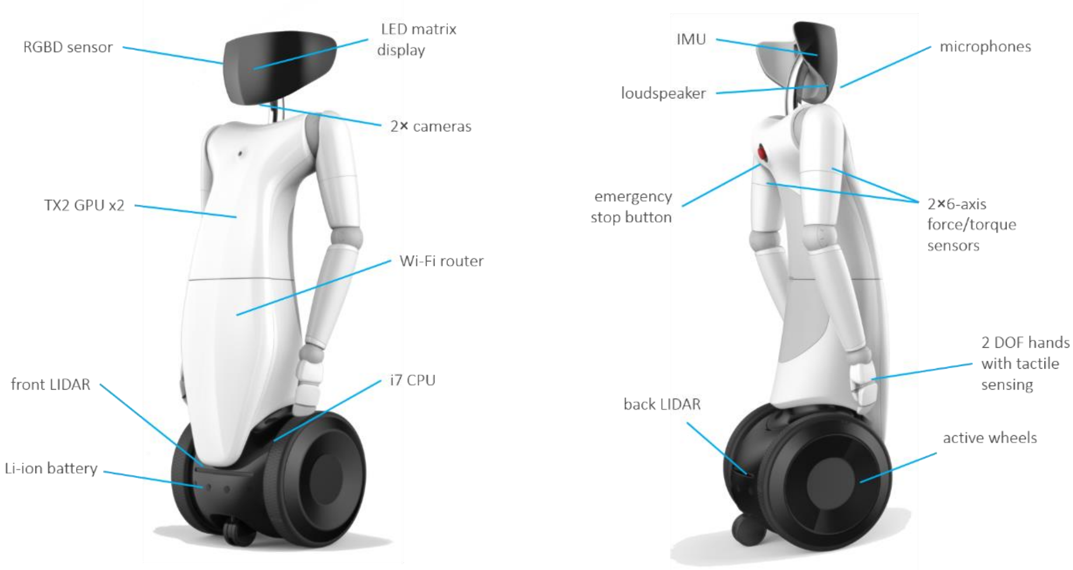

Figure 29 – The humanoid robot R1

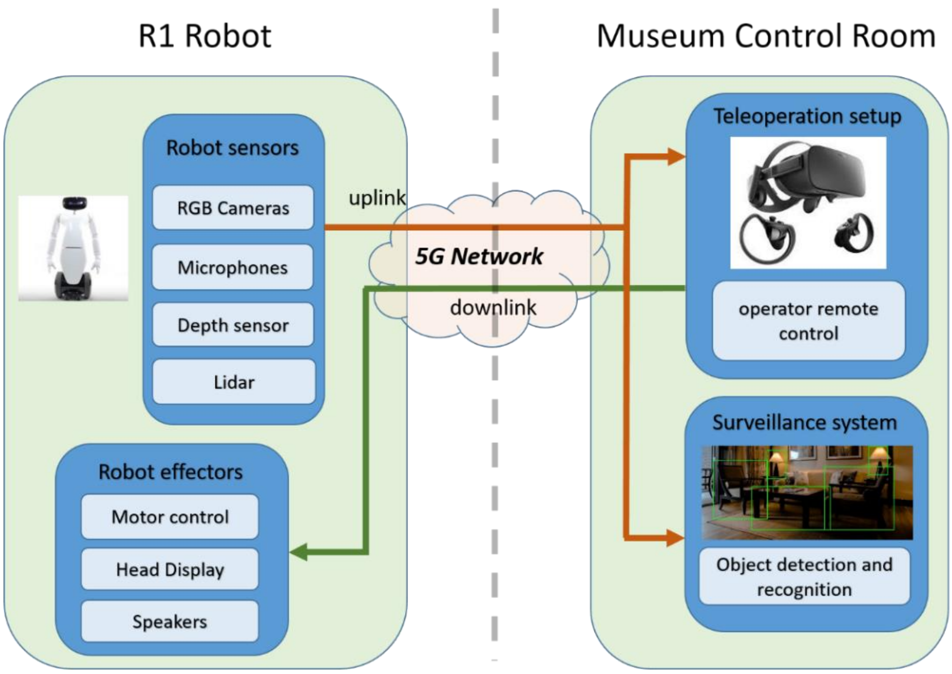

Figure 30 – Application components for R1 surveillance task

Smart cities

As previously mentioned, the surveillance activity will be enriched by informing the remote operator regarding critical events that may be happening in the museums (e.g. fires, structural failures). To this extent, an underlying IoT platform will be used to convey the information gathered from oscillation and fire sensors that will be placed inside the museum:

- Oscillation sensors (Figure 31) monitor real-time fluctuations, failures and structural variations of buildings. They must be installed on the floor (preferably one sensor for each floor of the building). The device requires a power source and its size is about 10cm x 15cm x 5cm. The collected information is conveyed to the IoT platform using a Narrowband IoT (NB-IoT) connection.

Figure 31 – Oscillation sensor

- Smoke sensors (Figure 32) constantly monitor the presence of CO and CO_2. They must be installed on the roof of each room and requires a power source. The collected information is conveyed to the IoT platform using a NB-IoT connection.

Figure 32 – Smoke sensor

The data acquired from structural sensors and smoke detectors are sent and stored on an IoT platform and then analyzed by an algorithm able to detect any critical issues and send reports to security personnel. Historical and real-time information on measured data can be viewed by museum administrators through control dashboards (Figure 33).

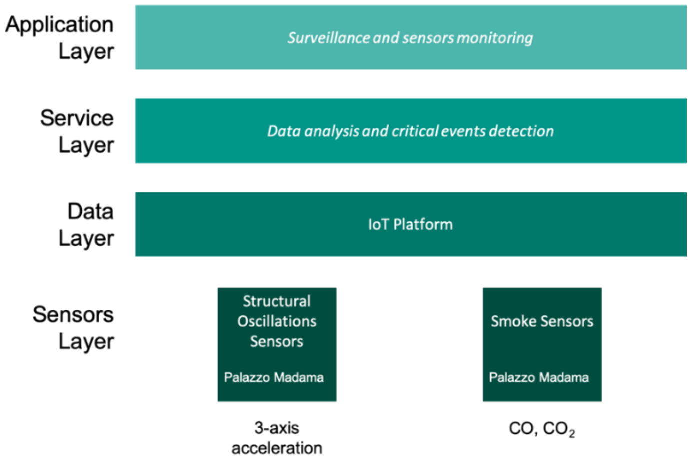

Figure 33 – IoT Critical Event Monitoring architecture

3.2.3.2 Trial description

For the scenario with the Double robot, there are no particular differences in the planning of the trials with respect to the previous sub-use cases. The scenario with the R1 robot will be enacted and carefully tested by IIT and ERI-IT in ERI-IT premises in Genova, using networking equipment that closely matches the one available in Turin. This will ensure that major issues will be detected and solved before trials execution.

At a first stage, the locations for the trial will be Palazzo Madama and GAM. Both Double robot and R1 humanoid robot will report to the identified control rooms, sending real time footage while patrolling areas of the museum. In this application real-time, high-quality footage will be fundamental requirements to ensure a quick human response in case any problem should arise in the museums.

Table 6 contains the main activities planned for UC2.c:

Phases & timeline	Description
Phase 1: Site inspection	Definitions of the location, site visit, check of the environment to identify areas where the robot can move safely. Check for potential barriers, localization issues and preliminary evaluation about the required beacons installation. Verification of NB-IoT coverage and performances.
Phase 2: Application specification	2.a: Robot's Remote control application and backend specification
	2.b: Specification of front-end and back-end functionalities required by the IoT Web Dashboard
Phase 3: Application development and devices integration	3a: Remote control application and backend development, robot API integration
	3b: Development of sensors' firmware and IoT Web dashboard software components.
Phase 4: Deployment and Test of the network	Integration of the solution with radio connectivity, validation in laboratory environment at TIM.
Phase 5: Deployment of control room and robot	Setup and deployment of robot and sensors in the museum and control room in security building, preliminary test
Phase 6: Beta Test of application	Test with the robot in TOR with 4G / 5G
Phase 7: Test of application in real condition	Test with the robot in TOR with 5G
Phase 8: Monitoring and Evaluation	Evaluation of results from phase 7, improvement of the application, preparation of the final test

Table 6 – UC2.c Phase of the Trial

3.3 UC3 - Robot-assisted museum guide

The goal of this use case is to leverage robotic technology to provide an enhanced museum visit experience, improving the efficiency of safety monitoring aspects in the museum at the same time.

Figure 34 – Concept of robot-assisted museum guide

In this use case, the humanoid robot R1 is deployed inside the museum (Figure 34). A map of the environment, enriched with the location of the main attractions, is stored in the system, allowing visitors to interact with the robot, asking information on what they can see and where. Visitors will be able to interact with the robot in two different ways, i.e. statically and dynamically, as described below.

At the main entrance, or in common areas inside the museum, R1 will be able to provide basic information about collection highlights and temporary exhibitions, as well as the location of notable points, such as vest rooms, toilets and security exits. During queuing time at ticket desk, R1 will assist visitors giving them real time information about the line and prospect waiting time. Inside the museum, instead, the robot will be able to physically guide visitors to the attraction, moving through the rooms of the museum and describing the artworks. This guided tour will be performed autonomously by the robot, which will navigate in the environment following a precomputed path. Human intervention will be required only in emergency situations needing an immediate reaction. For example, the robot will be able to monitor the presence of people in areas that are forbidden to the public during the tour and deliver a warning if a violation of the rules takes place. In this case, depending on the situation, the operator will be able to decide to stop the autonomous tour and eventually take control of the robot manually.

To perform all of these tasks, information such as the sound from the microphones, the RGB and depth images from the cameras and the Light Detection and Ranging (LIDAR) measurements will need to be reliably transmitted over the 5G network.

Additional robot intelligence in need of high amount of computational resources is required for this task, which further motivates the use of computing power external to the robot such as computing cluster. Low latency and high bandwidth communication are thus mandatory for a proper implementation of this use case.

3.3.1 Application Components

The main application components required by this use case are shown in Figure 35.

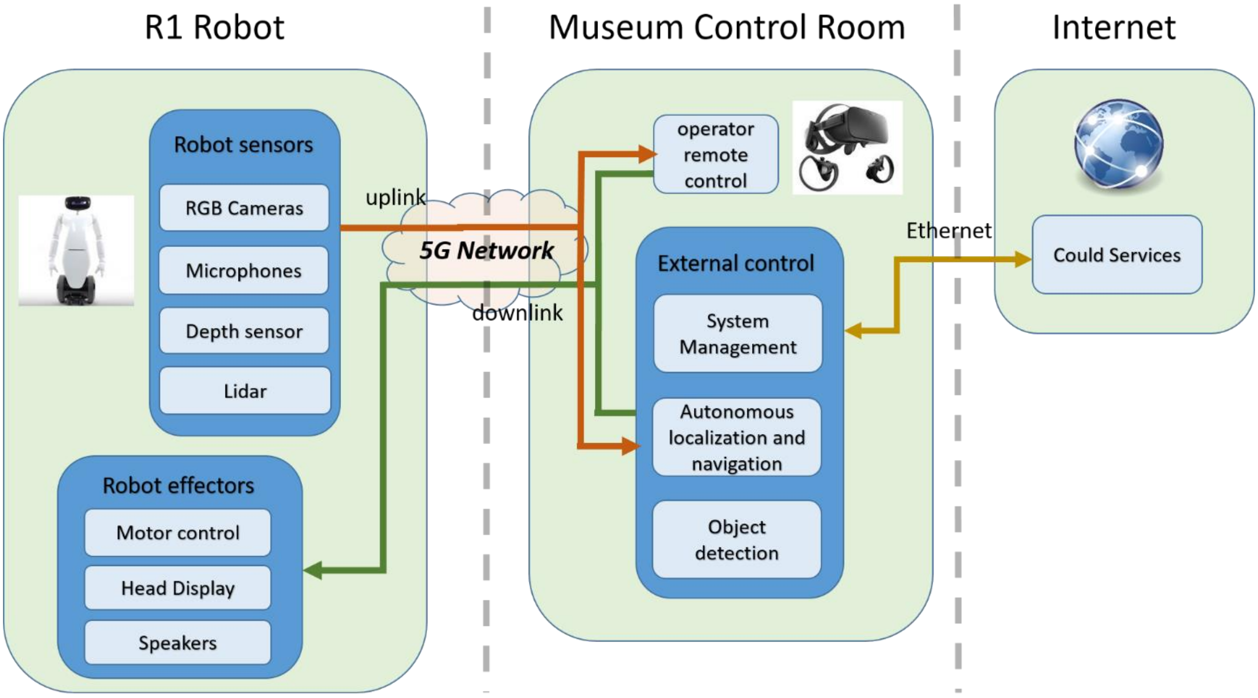

Figure 35 – **Main Application components**

The autonomous navigation module, developed by IIT specifically for the R1 robot, is responsible for computing the robot trajectory when moving through the museum rooms, given a pre-computed map of the environment. The map will be built by IIT, using standard Simultaneous Localisation and Mapping (SLAM) techniques. An operator will manually refine the map, adapting it to different exhibitions and identifying keep-out areas such that the robot will be able to safely navigate the environment.

During the guided tour, a surveillance application will run concurrently, streaming the video captured by the robot to a control room in real time. In this way an operator will be able to immediately take control of the robot if an unexpected event occurs. The images will also be processed in the control room running people-detection or other object-detection algorithms based on machine learning techniques. These algorithms will be ableto detect whether a tourist is approaching too close to a piece of artwork or a forbidden area, if an unexpected object has been left on the floor, etc.

Additionally, Comune di Torino will provide the description of the tour inside the museum, including the path the robot has to follow on the map and the locations of the artworks. This description will also include the dialogue tree, i.e. a description of the answers that the robot is supposed to give to the visitors when they ask a question. The software for natural language processing will be integrated on R1 robot by IIT, using third-party, cloud-based services.

3.3.2 Trial description

The location for this use case are Palazzo Madama and/or GAM, according to the site facilities and conditions, to be best investigated during the operational design phase. The scenario will be enacted and carefully tested by IIT and ERI-IT in ERI-IT premises in Genova, using networking equipment that closely match those available in Turin. This will ensure that major issues will be detected and solved before trials execution.

The setup will consist of:

- the R1 humanoid robot (provided by IIT),
- the computing equipment for robot control (i.e. the remote brain of the robot). The equipment consists of a server powered by a high-performance NVIDIA Graphics Processing Unit (GPU). This equipment

is required to perform efficient video processing, to compute the robot trajectories and detect people and objects in the environment,

- multiple radio beacons (Ultra Wide Band (UWB) devices) installed in the exposition rooms to improve robot localization, if the environment in which the robot will navigate is challenging (a preliminary check of the museum map will be performed,
- the equipment for robot teleoperation in the control room. The minimum requirement includes a laptop and a joystick controller (VR headset optional).

The trials in the museums of Turin will consists of testing sessions of short duration (~1 week) that will be repeated during the project durations. The provisional number of testing is sessions: 3-5.

Detailed organization of the trial and timeline are listed in Table 7.

Phases & timeline	Description
Phase 1: Operative planning (site inspections, definition of maps; confirmation of requirements; meeting with Museum Directors)	Definition of the location, site visit, check of the environment to identify areas where the robot can move safely for the guided tour. Check for potential barriers, localization issues and preliminary evaluation about the need beacons installation.
Phase 2: Definition of the interaction strategy/storytelling (e.g. confirmation of target user; creation of the storytelling, definition of the engagement campaign; creation of contents)	Definition of the guided tour path, user interaction, robot dialogues.
Phase 3: Development of vertical application (1)	Software development and validation in laboratory environment.
Phase 4: Realization of the accompany phase target to users	Robot testing in TOR, building of maps, evaluation of navigation performance
Phase 5: Deployment and Test of the network	Integration of the solution with radio connectivity, validation in laboratory environment at ERI-IT.
Phase 6: BetaTest of application	Test with the robot in TOR with 5G
Phase 7a: development of vertical application (2)	Preliminary test phase in laboratory environment.
Phase 7b: Test of application in real condition (detail the plan of testing: sub-phases/duration)	Test with the robot in TOR with 5G
Phase 8:Monitoring and Evaluation	Evaluation of results from phase 7, improvement of the application, preparation of the final test
Phase 9: Validation	Final Validation with the robot in TOR

Table 7 – UC3 Phase of the Trial

3.4 UC4 - High quality video services distribution

This use case targets the distribution of enhanced high-quality video services for tourists providing immersivity functionalities to the user experience. It is directly related to the media and entertainment vertical, as part of the touristic city. Users will use their smartphones, tablets, AR devices and monitors to receive educational and informative content during their visits to the city and its museums. In addition, a specific professional 4K-HDR video will be produced in collaboration with the RAI Television Production Center. This audio/video (A/V) product will be used for both testing and promotional activities about the city and its culture.

In this use case, the contents will be simultaneously distributed to a large number of users by relying on the use of advanced multicast and broadcast technologies. Their experience will be additionally enhanced with the use of object-based content transmission. In this type of transmission, the content is divided into objects (video elements, audio elements, captions, subtitles, music type, etc.) for delivering the information to users with different requirements and preferences. This permits to provide a personalized experience that is especially useful when considering many tourists from different countries, i.e. speaking different languages. It is also very useful when transmitting content to different types of devices, since the type of content can be configured and transmitted with specific size and resolution.

On the other hand, the distribution of immersive, high quality and personalized video content/services for tourists are also key aspects to demonstrate. Immersivity lies in providing the user with additional content related to the surrounding environment (in the form of text, pictures and video on the monuments, objects in a museum, etc.) by using smartphones and/or HoloLens-like devices.

The main target users of this use case are tourists, students and citizens in general who visit the museum and the city of Turin and would like to improve their personal experiences. These users are expected to benefit by the distribution of enhanced high-quality video services providing immersive functionalities to the user experience. The trials of this use case will be done in the city of Turin. In particular, they will take place in Palazzo Madama, its surroundings and the other locations to be defined as the project progresses.

The objective is to provide the aforementioned services by using two infrastructure deployments. The contents could be received from mobile cellular networks, where an MNO transmits the content using a mixed mode. In this case, both multicast and unicast components share resources. The second option is to transmit the content via broadcast networks, according to which the content is transmitted to all users at once by using a fixed amount of network resources in a consistent manner.

3.4.1 Application Components

The use case will generate broadcasting applications for distributing immersive contents for tourist and students. As explained above, part of the content needs to be personalized and there is also information being delivered by the user in the uplink. The use case will be developed in the following trials:

Mixed unicast/broadcast services in cellular networks

This use case makes use of an MNO-centric approach. Here, the content is transmitted via the cellular 5G network of ERI-IT in a mixed mode where multicast and unicast services share the same resources. With this option, it is possible to distribute immersive contents to a large number of users, where part of the downlink content needs to be personalized and where information is also being delivered by the user in the uplink. The trials will be divided in several stages of implementation and demonstration.

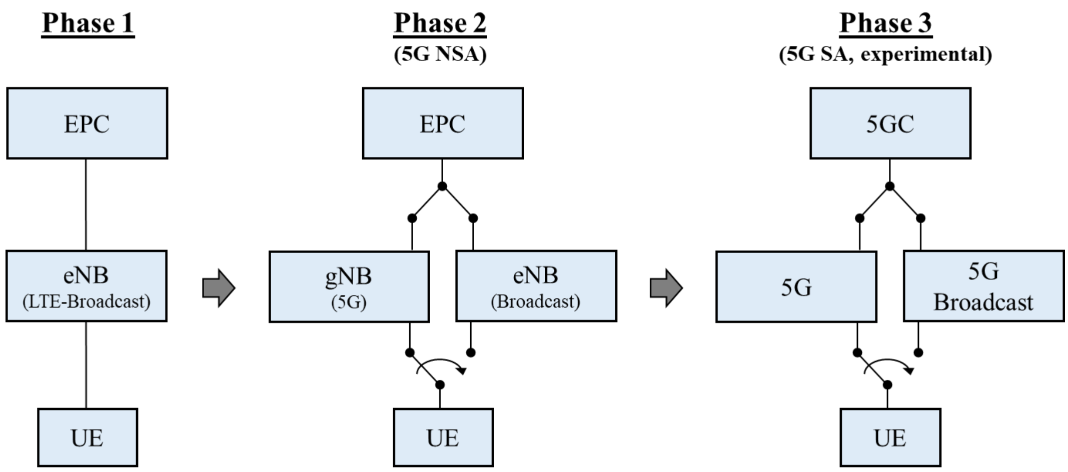

Figure 36 – Mixed unicast/broadcast services components, divided into three stages.

- Phase 1 - LTE with enhanced Multimedia Broadcast Multicast Service (eMBMS) capabilities. This step encompasses the implementation of LTE broadcast capabilities in the RAN. Some additional features that are needed in the core network are the integration of a Broadcast Multicast Service Center (BM-SC), MBMS Gateway (MBMS-GW) and a Mobility Management Entity (MME) with multicast capabilities. Additionally, the User Equipment (UE) needs a middleware and support for MBMS. The network is able to provide a switch between unicast and broadcast according to the audience size.

- Phase 2 - 5G non-standalone with eMBMS capabilities. In a second stage, the network will provide the capability to switch between 5G New Radio (NR) unicast and 5G LTE-based, as required by the number of users.
- Phase 3 - 5G standalone with broadcast capabilities. The project will also seek the potential implementation of a 5G standalone core network with multicast/broadcast capabilities. Although this option is not yet specified in 3GPP, a Study Item has been approved recently by 3GPP SA2. A first theoretical approach to this option was also explored in the 5G-Xcast project.

5G Broadcast delivery to massive audiences

The second option is a broadcast-centric receive-only approach, where RAI's infrastructure is used. This use case utilizes a High-Power High-Tower (HPHT) topology to transmit the content to all users at once. The trials will be divided into two phases as follows:

- Phase 1- 5G Broadcast – enhanced Television (enTV) Rel-14. This stage consists of transmitting 3GPP further evolved MBMS (FeMBMS) services to all users by using a broadcast tower. RAI already tested this technology under different scenarios, such as the European Championships 2018 in Aosta Valley, the Feast of San Giovanni or the RAI-CRITS tests mobile TV broadcast demonstrator.
- Phase 2 - 5G Broadcast - enTV Rel-16. In this stage, the consortium is committed to update 5G Broadcast to Rel-16 and explore the advantages that this technology brings to real users such as citizens or tourists. Expected improvements are a larger coverage or higher mobility speeds.

3.4.2 Trial description

The 4K-HDR products will be trialed in these use cases to stress the network capabilities in order to evaluate the performance in different content transmission modes (multicast/broadcast and unicast). To do so, the TV production center of Turin will be involved. This type of content will be used also for promotional activities of the project. The trial will make use of all computing equipment needed for video processing and content distribution. As for the users, TV sets, smartphones and/or HoloLens-like devices will be used to receive and show different content in specific transmission modes. These devices are also used in UC1. The estimated duration of this trial is 30 months, starting from M7 with a final demonstration at the end of the project. There will be several phases as specified above. There is a possibly of self-maintaining after the project (to be studied). The specific phases (Table 8) in which the implementation and validation of this use cases is divided are the following.

Phases & timeline	Description
Phase 1: Use case definition and technical requirements planning	The first phase implies the design and definition of the use case and its application components. The technical requirements and equipment specifications must be clearly defined for future deployments.
Phase 2: infrastructure deployment and system integration	Implementation of the LTE broadcast capabilities in the RAN, as well as the additional features in the core network needed for the MNO-centric approach.
Phase 3: phase-1 trials	Trials of 5G non-standalone with eMBMS capabilities and 5G Broadcast - enTV Rel-14, using Ericsson and Rai's networks respectively.
Phase 4: phase-2 trials	Second phase of both use cases, including implementation and trialing. The unicast/multicast switching will be tested for the first approach. enTV Rel-16 trials will be performed in parallel.
Phase 5: potential improvements	The project will also seek the potential implementation of a 5G standalone core network with multicast/broadcast capabilities.

Table 8 – UC4 Phase of the Trial

3.5 UC5 - Remote and distributed video production

The main objective of the use case is to exploit the 5G-TOURS network features for remote television production and analyze how 5G networks could support various scenarios in which high-quality video (e.g., in 4K, HD/HDR or Video 360°) is generated and transmitted. In a typical TV production environment, video contents is delivered from cameras located in places where an event is taking place to a TV studio in the broadcasting center or to a remote studio facility on the event location itself. Such video contents could be used both for immediate live broadcasting of the event or recorded to be further edited and used in TV programs later on.

In distributed TV video production, the content needs to be produced by mixing local and remote audio and video contributions in the TV studio. The remote contributions are thus delivered to the main editing site via the 5G network in real time. The challenge in this scenario is the end-to-end delay between the local and the remote site, which must be kept very low and constant. Furthermore, each AV flow at the remote site can be only mildly compressed before transmission to preserve sufficient headroom for editing and distribution coding, so the content size needs to be large. On the other end, the number of required remote flows is planned in advance and kept fixed during the program production. The final program can then be distributed to the users either live or at a later time.

Introducing 5G technologies, MNOs will offer new services for remote distributed production in city areas allowing customers such as broadcasters and media companies to use new tools to produce television content, the personnel involved in the production of a television program include creative talent such as actors, directors, writers, and producers as well as technical crew members such as camera operators, electrical technicians, and sound technicians.

Currently almost all TV content producers are using what in popular language is called "backpack unit" for video transmission in remote areas. The backpack unit bundles multiple 4G connections together to transmit the video signal back to the TV studios for further processing. This use case will demonstrate how the 5G-TOURS architecture will improve the available bandwidth of live connections (real-time transmission) and enable low delays leveraging on features of 5G network. The 5G-TOURS system will enable the increase of bandwidth used for live connections, providing specific slices with a guaranteed Quality of Service (QoS). Furthermore, 5G-TOURS architecture could enable video processing at the very edge of the network instead of studios, reducing high production costs of multi-camera events covering.

Introducing remote production over 5G networks for television content can revolutionize the typical work flow of broadcaster and media companies. The use case is extremely challenging, and requires very low and stable delays, an ultra-reliable capability and a very large bandwidth capacity in order to reach a good final result.

One of the biggest challenges in this use case is to realize an itinerant orchestra, where, the event is a concert performed by an orchestra with some musicians located in the main concert hall and some other itinerant musicians walking in the streets while approaching the concert hall. Each itinerant musician is followed by a cameraman shooting their performance and providing cues to stay synchronized with the main orchestra performance. The high-quality AV signal (HD, 4K, Video 360°) is streamed via the 5G network to the main editing facility where it is properly processed and mixed with both the orchestra located in the concert hall and the rest of the itinerant musicians. The spectators in the concert hall will see the itinerant musicians on a Light Emitting Diode (LED) wall and listen to their performance via an amplification system, mixed with the local orchestra, until they enter the concert hall and join the orchestra. The overall performance will also be recorded for future broadcast distribution. Figure 37 shows a typical situation in which a mobile TV studio is used in covering of a live event.

Figure 37 – **A typical situation of mobile TV production**

The purpose of this use case is to exploit the new 5G network features to improve the production flow of TV program content creation, enabling the transmission of data (video, audio, management control and data enrichment) from where the action takes place to a remote-control room where the final product will be assembled for the recording or the transmission. Irrespective of whether shooting for the production of services, advertisement, fiction or coverage of live events to be aired live is taking place, the 5G technologies will involve a streamlining of the effort required by media companies in content creation.

The main service level objectives of this use case are:

- improving video quality of live connections (real-time transmission)
- enabling the mobile unit to utilize more bandwidth (provisioning a specific slice with a guaranteed QoS)
- enabling the use of edge computing processing capabilities for production of video contents at the edge of the network
- supporting the work flow typically used from broadcasters and media companies
- grant low delays and data flows synchronization.

The purpose of the use case is to contribute to the valorization of cultural events taking place within the territory of the city introducing a new way to cover live events, while at the same time build a more efficient and cost-effective way to produce television content. This aspect will also improve local, national and international tourism with social and economic utility for cities.

The main target users of the use case is media companies which are massively involved in content creation. The personnel involved in the production of a television program include creative talents such as actors, directors, writers, and producers as well as technical crew members such as camera operators, electrical technicians, and sound technicians.

This use case will verify that the exploitation of new network technologies can increase the productivity of content and improve the whole work flow for the television production. At the same time new services and new television formats could be created by joining new technologies and creative people in the city of Turin, where the covering of the 5G-TOURS network will be provided around remote or fixed TV studios.

The distributed production use case will allow the video contents to be delivered from cameras located in places where an event is taking place to a TV studio in the broadcasting center or a remote studio facility on the event location itself. Such video contents could be used both for immediate live broadcasting of the event or recorded to be further edited and used in TV programs later on (linking the UC4 about video distribution).

3.5.1 Application Components

In case the video production is distributed, the content needs to be produced by mixing local and remote audio and video contributions in the TV studio. The remote contributions are thus delivered to the main editing site via the 5G network in real time (Figure 38).

The typical multiple camera method is used for shooting inside or outside a studio. A number of cameras are focused on the action taking place on the set, and scenes are shot in sequence. Each camera operator works from a list of camera positions and framing requirements for the full scene. Together the cameras cover all required view angles. A portable LiveU video transmission unit allows the transmission of live content from cameras to the remote control/mixing room. These units will allow high quality video transmission over one or more low latency connections. The end-to-end latency of the video transmission will be as low as possible, also taking into consideration the location of the streaming server closed to the edge of the network.

Using headsets to communicate with the camera crew, the director can ask for camera adjustments during the filming of the scene and indicate to the technical director which cameras to use at each moment. The technical director ensures the selected shot is recorded. Additionally, the itinerant orchestra use case flow is constituted of two consecutive parts. The first part includes the transmission of high-quality video from multiple locations to a local/remote studio whereas the second part includes video production and live video broadcasting to a wall LED screen as well as to spectators' devices.

For recording and streaming of high-quality video from different locations, both the remote musicians as well as the ones that will be located at the main concert hall will be accompanied by one or more camera men that will be equipped with a high definition camera connected to a portable LiveU video transmission unit carried in a backpack. These units will contain one or more 5G compatible modems for transmitting high-quality video over one or multiple low-latency connections. Since the end-to-end latency of the video transmission must be kept as low as possible, we will consider locating the streaming server (i.e. the server that is responsible for bonding the multiple channels and decode the video streams) as close to the edge as possible. The server will send raw (uncompressed) video streams to the production system that will be then used for producing and broadcasting the video to the different destinations.

One of the biggest challenges in this use case is to synchronize the audio coming from the different sources and ensure that all musicians are playing in sync with each other. In order to maintain such synchronization, we will use Interruptible Foldback (IFB) - one-way communication channel from the director or the orchestra conductor to the multiple remote locations.

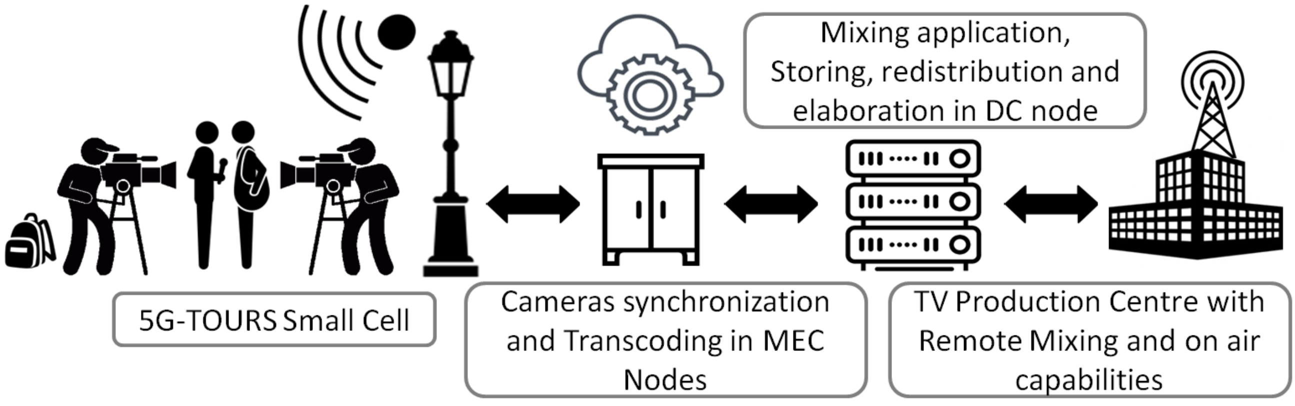

Figure 38 – **UC5 high-level scheme of the application platform**

3.5.2 Trial description

In this use case the final A/V content will be produced by mixing local and remote audio and video. The remote contributions are delivered via the 5G network to the main editing site in real time. The challenge in this scenario is to keep very low and constant the end-to-end delay between the local and each remote site.

The basic functionalities of this use case will be developed during the first half of the project and they will be exploited as base points to realize the itinerant orchestra example during the second half of the project. In particular, for the TV production and itinerant orchestra trials, we plan to build an incremental environment. The first step is to arrange the entire technical infrastructure for the television production which enables the second step (the itinerant orchestra) in which a few musicians will be involved to test the whole system. The last step will be the organization of an event with the involvement of a real orchestra.

In the first phase of the experimentation, the trial scenario will use the 4G network which will converge towards the 5G network infrastructure during the second stage, enabling the performance improvement through the usage of the Ericsson NR technology and additional features such as slicing to grant the requirement matching.

The purpose of the use case is to give a new experience of a concert performed by an itinerant orchestra contributing to the valorisation of cultural events taking place within the territory of the city. This aspect will also improve local, national and international tourism with social and economic utility for cities. The final user will have a new experience in live events, and at the same time media companies which are massively involved in content creation will test and verify that the exploitation of new network technologies will increase the productivity of content improving the whole work flow for the television production.

Joining new technologies and creative people is one of the key point in this scenario allowing the creation of new television formats. Trials in Turin will be located in 5G covering areas closed a television control room and an auditorium.

Trials will have a final performance of the itinerant orchestra in which some musicians that are moving in the street will be able play together with the other that are in the main concert auditorium. People in the auditorium will see the itinerant musicians on video walls and the sound will be mixed to the real local orchestra.

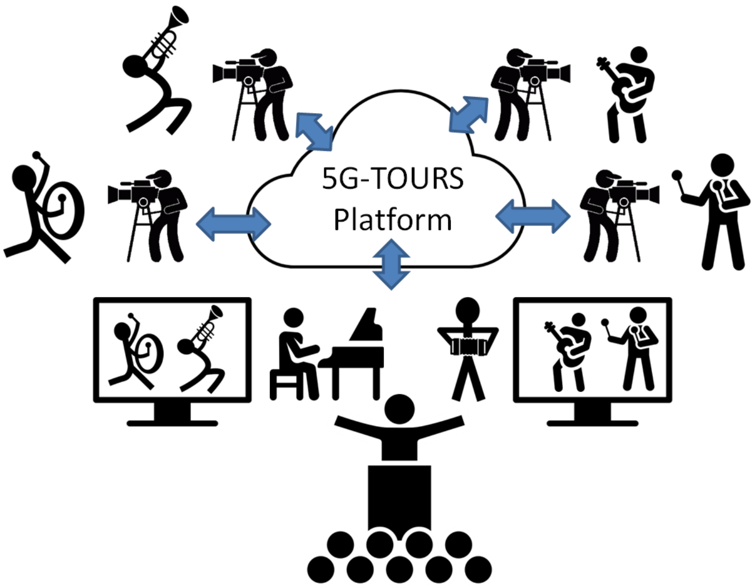

Figure 39 – **The itinerant orchestra work flow**

The trial site will be the city of Turin, and the exact locations are to be defined according to the network coverage available in the areas where remote musicians are moving and the auditorium where the event takes place (e.g. the auditorium RAI "Arturo Toscanini"). The main trial sites in Turin include:

- Mile of innovation in Turin
- Auditorium RAI "Arturo Toscanini"

The use case will be developed in the following two consecutive trial phases (Table 9):

- First trial phase: TV remote production
- Second trial phase: The itinerant orchestra

Phases & timeline	Description
Design and technical definitions	Design and understand the main components needed in order to deploy the entire solution. Collect all the specification needed (e.g. backpack specs from LiveU, network from Tim ecc..)
Development, system integration and preliminary functional test	1. preliminary functional test with camera+backpack+5gNetwork 2. evaluation of latency availability reliability 3. results discussion (Camera+Backpack+5G network capabilities)
First on-site trial and functional test	GOAL: Deploy all system part, including remote video/audio control-room, and functional tests with all the systems up and running.
Second on-site trial with orchestra	Technical and operational test with real use case scenario. That involves also a real orchestra with a real orchestra performance, but without the audience
Final trial-Main Event	Main-event with all systems up and running, real event with orchestra and audience

Table 9 – UC5 Phase of the Trial

4 Network Infrastructure

The initial infrastructure is defined by the 5G-EVE project [13] that is already in the execution phase and is developed, for the Italian site, in Turin. The network infrastructure is based on Ericsson solution, 3GPP Rel-15.0 5G NSA infrastructure. The Non Standalone (NSA) architecture provides connectivity for combined LTE and NR systems where LTE provides the control plane function while LTE and NR are used for the user plane. The 5G Ericsson deployment is supported in the Ericsson Radio System and Evolved Packet Core (EPC) solutions.

The main components of the network solution are summarized below:

- RAN: Radio Access Network composed of LTE and NR radios and basebands (Digital Unit) connected to the transport layer inside 'TIM Field TO' block.
- Transport: Routers to implement backhaul and fronthaul to implement optimized baseband/radio interconnection.
- Core solution: the main components are the Home Subscriber Server (HSS), the MME, the Evolved Packet Gateway (EPG) and the Ericsson Network Manager (ENM) available both on TIM field and TIM lab installations.
- Vertical application servers: installed at Politecnico Torino and connected to the TIM Lab.

A diagram representing the current solution of 5G-EVE is summarized in Figure 40:

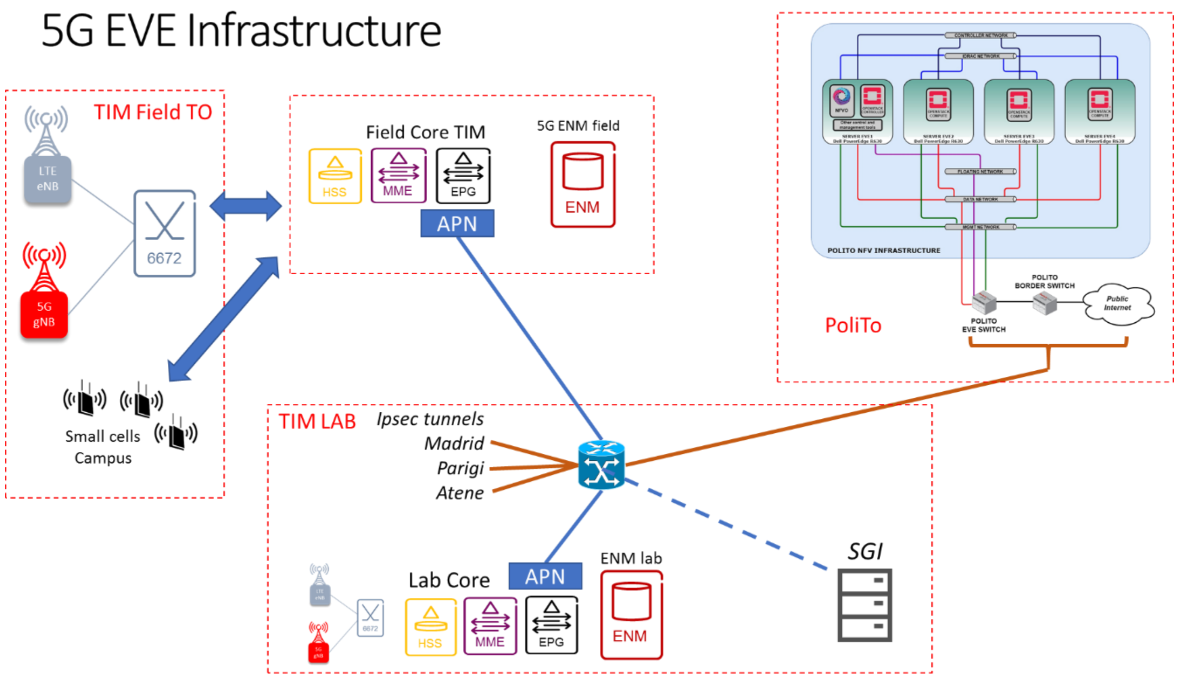

Figure 40 – 5G-EVE network components solution

As the above network is assumed to be the baseline, some topics are under investigation from the 5G-TOURS project as additional requirements to 5G-EVE to match the needs of the considered use cases. For this reason, the following topics have been the subject of analysis during WP2 requirement definition providing a baseline of the network infrastructure characteristics and components needed by 5G-TOURS to satisfy the identified KPIs. As a result of this analysis, four development areas are considered from a network perspective:

- Ensure 4G/5G connectivity in all trial locations (indoor and outdoor),
- Capture bandwidth and latency requirements of all use cases as a differentiator of 5G technologies,
- Implement a broadcast functionality, such as Ericsson LTE eMBMS (low-tower, low-power) and/or TV broadcast service (high tower, high power) solutions,

- Identify an orchestrator solution to implement slicing in the most effective way.

In top of the main development areas, the following specific needs have been identified for each use case implementation, which are treated as preliminary requirements. In addition to the latency and bandwidth requirements of the XR scenarios, the use case 1 also requires the coexistence with an IoT network, characterized by network performance requirements that can vary dynamically. The frequency of the data sent by the sensor, especially in the case of structural oscillations or fires, is subject to variations, based on the level of criticality that is detected. The type of transmission, typically a burst of data, also requires low latency so that data to be analyzed in a short time. The service layer provided by 5G-TOURS will support the dynamism of the IoT scenario and its coexistence, under the same network infrastructure, with highly resource-intensive scenarios such as those of VR.

In the first phase of the use case 1 experimentation, the sensing stations will use the 4G operating network and, in a second stage, a NB-IoT network will be used. A proper NB-IoT coverage will thus be required to provide connectivity to buildings and outdoor spaces where the trial will take place.

Use case 2 implementation needs to ensure a good latency between the controller and the robot. Therefore software components of the system could require to be executed in the edge node (i.e. Multi-access Edge Computing (MEC)). The software deployment, functions definition and their mapping on the network components will be defined according to the implemented use cases.

To guarantee a complete use case 3 implementation Internet connectivity is required for cloud computing, e.g. to connect to software for natural language processing.

Apart from the network infrastructure and user equipment, there are several elements needed for the validation of use case 4. These elements are the following:

- RAN with 5G and LTE-broadcast capabilities in first stages and both 5G unicast and multicast if time permits.
- A 5G Core (5GC) network that includes the integration of key components, including a BMSC, an MBMS-GW and a MME with multicast capabilities.
- UE middleware with eMBMS support is also needed.

The aforementioned components will be implemented based on the 5G-EVE platform. In particular, the cellular network deployed in Turin will be used. The broadcast infrastructure from RAI will be additionally employed. Indoor coverage is key in use case 4 to provide the services to the visitors of the Palazzo Madama museum, but outdoor coverage is also needed for providing services in the rest of the city.

4.1 Preliminary use case technical requirements

From the initial analysis of the use cases addressed by 5G-TOURS, specifically for Turin Node, a requirement set, both general as well as preliminary technical requirements, has been specified.

The technical and network requirements are given in sufficient detail to define the scope of the use cases whilst avoiding over constraining the later design and they are part of the analysis and study of WP3. At the moment preliminary requirements analysis is available in Deliverable D3.1 “Use cases, deployment and techno-economic requirements - high level description” [6].

4.1.1 Use case 1

The implementations of the application require the coexistence of VR and IoT service, characterized by network performance requirements that can vary dynamically. The type of transmission, typically a burst of data, also requires low latency for the data to be analysed in a short time. The service layer provided by 5G-TOURS will support the dynamism of the IoT scenario and its coexistence, under the same network infrastructure, with highly resource-intensive scenarios such as those of VR.

In the first phase of the use case 1 experimentation, the sensing stations will use the 4G operating network and, in a second stage, converge towards the NB-IoT network. A proper NB-IoT coverage will then be required to provide connectivity to buildings and outdoor spaces where the trial will take place. Slicing type and preliminary technical requirements are shown in Table 10.

Name	Slice	Preliminary Technical Requirements				
		Density	Speed	Throughput	Latency	Reliability
Augmented tourism experience	enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), Ultra Reliable Low Latency Communications (URLLC)	~tens per $1km^2$	-	200 Mbps DL and ≥ 20 Mbps UL per device	≤ 15ms E2E	99.999%

Table 10 – UC1 Slice and preliminary technical requirements

The 4G and 5G capabilities and network requirements are shown in Figure 41 :

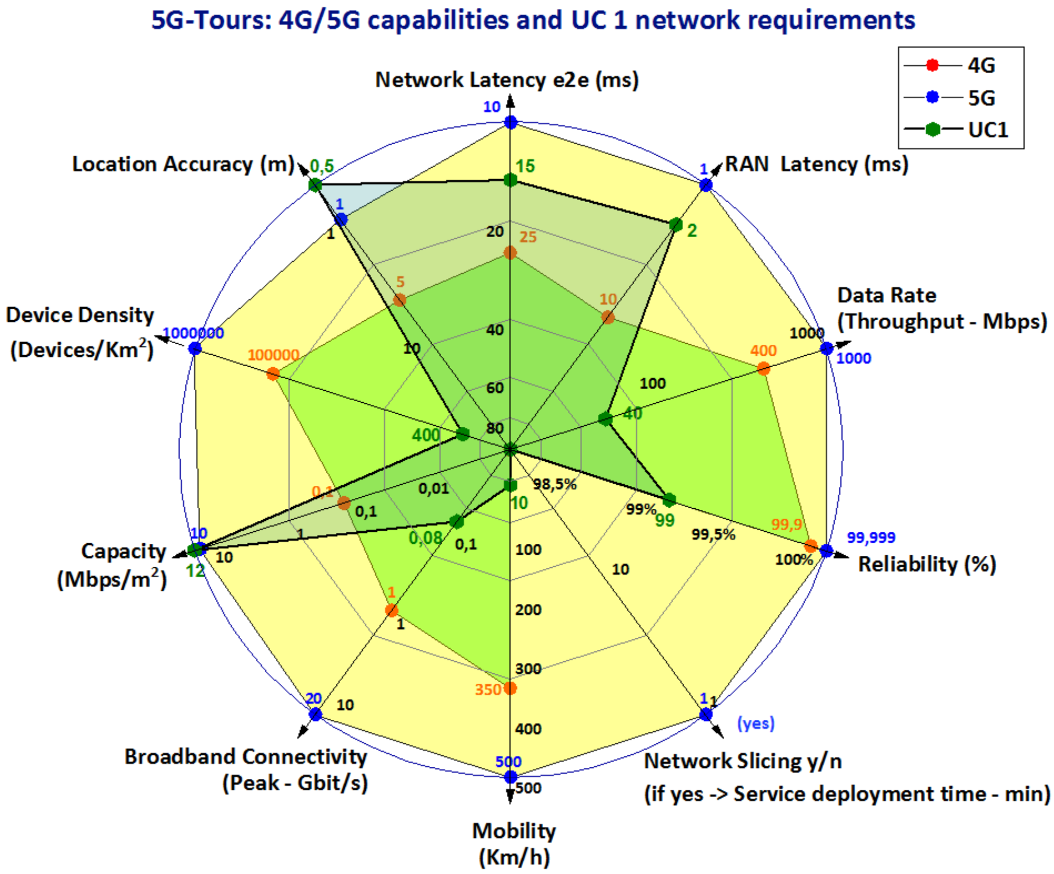

Figure 41 – 4G/5G capabilities and UC1 network requirements

4.1.2 Use case 2

UC2 implementation needs to ensure a good latency between the controller and the robot, some software components of the system could require to be executed in the edge node (i.e. MEC). The software deployment, functions definition and their mapping on the network components will be defined according to the implemented use cases. Slicing type and preliminary technical requirements are showed in Table 11.

Name	Slice	Preliminary Technical Requirements				
		Density	Speed	Throughput	Latency	Reliability
Telepresence	eMBB, URLLC	-	-	10 Mbps DL and 15- 20 Mbps UL	≤ 10 ms (bidi-rectional mode)	99.9999%

Table 11 – UC2 Slice and preliminary technical requirements

The 4G and 5G capabilities and network requirements are shown in Figure 42:

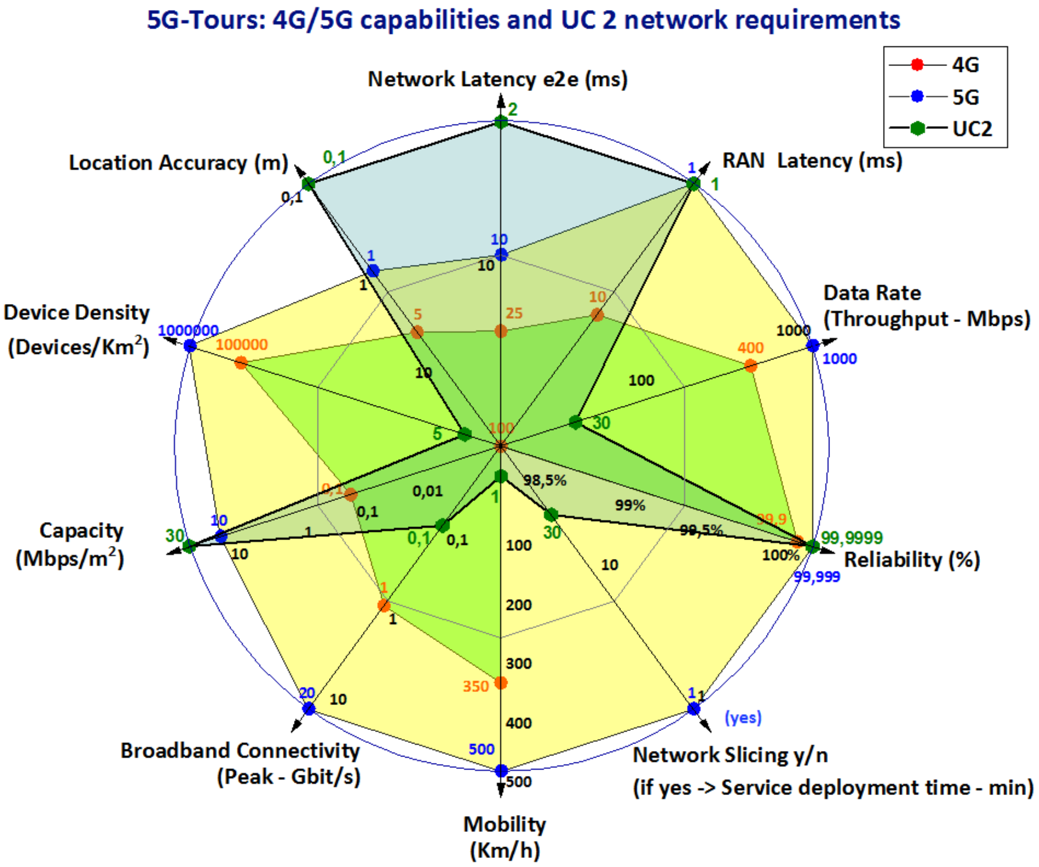

Figure 42 – 4G/5G capabilities and UC2 network requirements

4.1.3 Use case 3

To guarantee a complete use case 3 implementation the Internet connectivity is required for cloud computing, e.g. to connect to software for natural language processing. Slicing type and preliminary technical requirements are showed in Table 12.

Name	Slice	Preliminary Technical Requirements				
		Density	Speed	Throughput	Latency	Reliability
Robot-assisted museum guide and monitor-ing	eMBB, URLLC	-	-	10 Mbps DL and 15- 20 Mbps UL	≤ 10 ms (bidi-rectional mode)	99.9999%

Table 12 – UC3 Slice and preliminary technical requirements

The 4G and 5G capabilities and network requirements are shown in Figure 43.

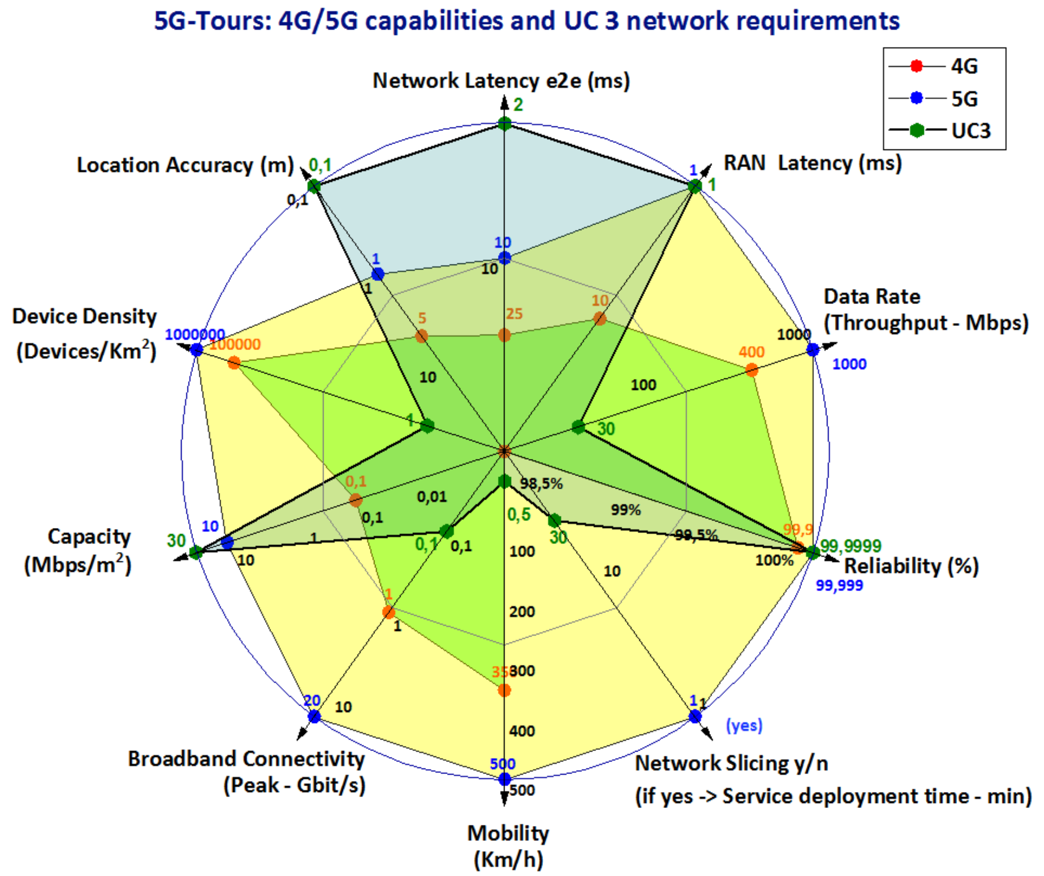

Figure 43 – 4G/5G capabilities and UC3 network requirements

4.1.4 Use case 4

Apart from the network infrastructure and user equipment, the following elements are needed for the validation of use case 4.

- RAN with 5G and LTE-broadcast capabilities in first stages and both 5G unicast and multicast if time permits.
- A 5GC network that includes the integration of key components, including a BMSC, an MBMS-GW and a MME with multicast capabilities, among others.
- UE middleware with eMBMS support is also needed.

The aforementioned components will be implemented based on the 5G-EVE platform. In particular, the cellular network deployed in Turin will be used. The broadcast infrastructure from RAI will be additionally employed. Indoor coverage is key in use case 4 to provide the services to the visitors of the Palazzo Madama museum, but outdoor coverage is also needed for providing services in the rest of the city. Slicing type and preliminary technical requirements are showed in Table 13.

Name	Slice	Preliminary Technical Requirements				
		Density	Speed	Throughput	Latency	Reliability
High quality video services distribution	eMBB, URLLC	-	-	≥ 25 Mbps	≤ 10 ms (bidirectional) N/A for PTM mode	99.9999%

Table 13 – UC4 Slice and preliminary technical requirements

The 4G and 5G capabilities and network requirements are shown in Figure 44.

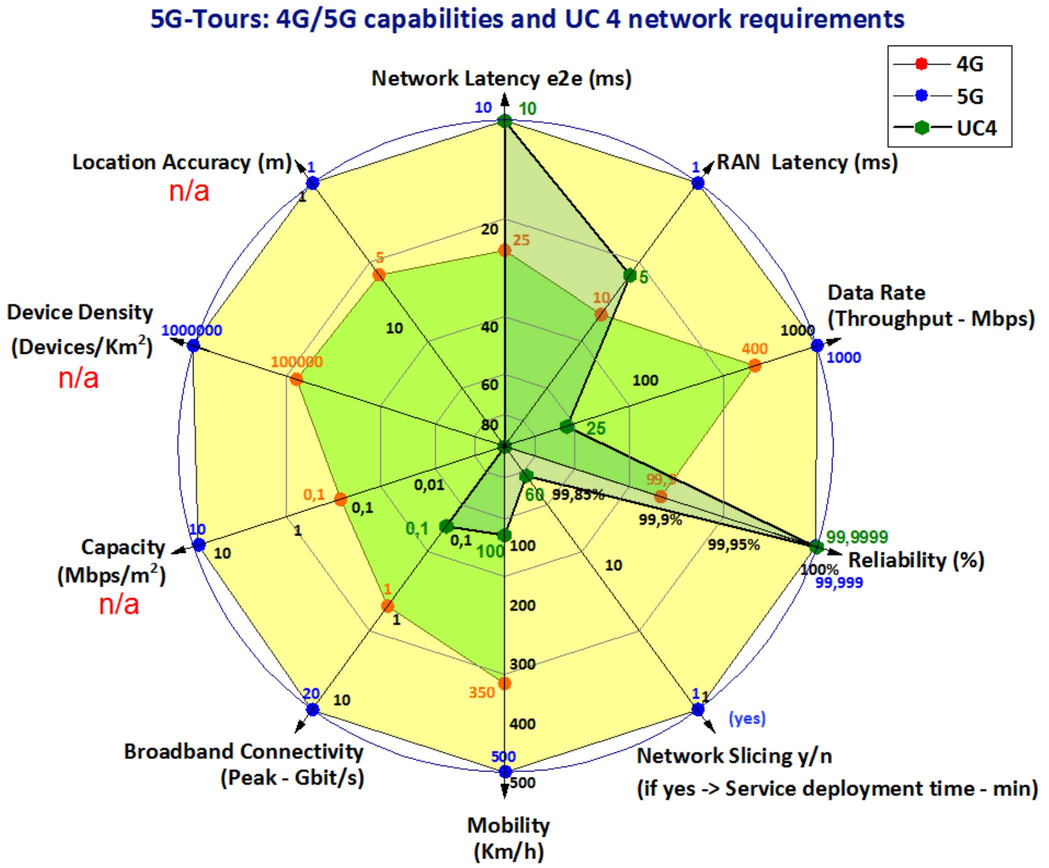

Figure 44 – 4G/5G capabilities and UC4 network requirements

4.1.5 Use case 5

Slicing type and preliminary technical requirements are showed in Table 14.

Use-case	Name	Slice	Preliminary Technical Requirements				
			Density	Speed	Throughput	Latency	Reliability
Use-case 5	Remote and distributed video production	eMBB, URLLC	-	-	≥ 25 Mbps (for each video)	≤ 10 ms (bi-directional mode)	99.9999%

Table 14 – UC5 Slice and preliminary technical requirements

W The 4G and 5G capabilities and network requirements are shown in Figure 45.

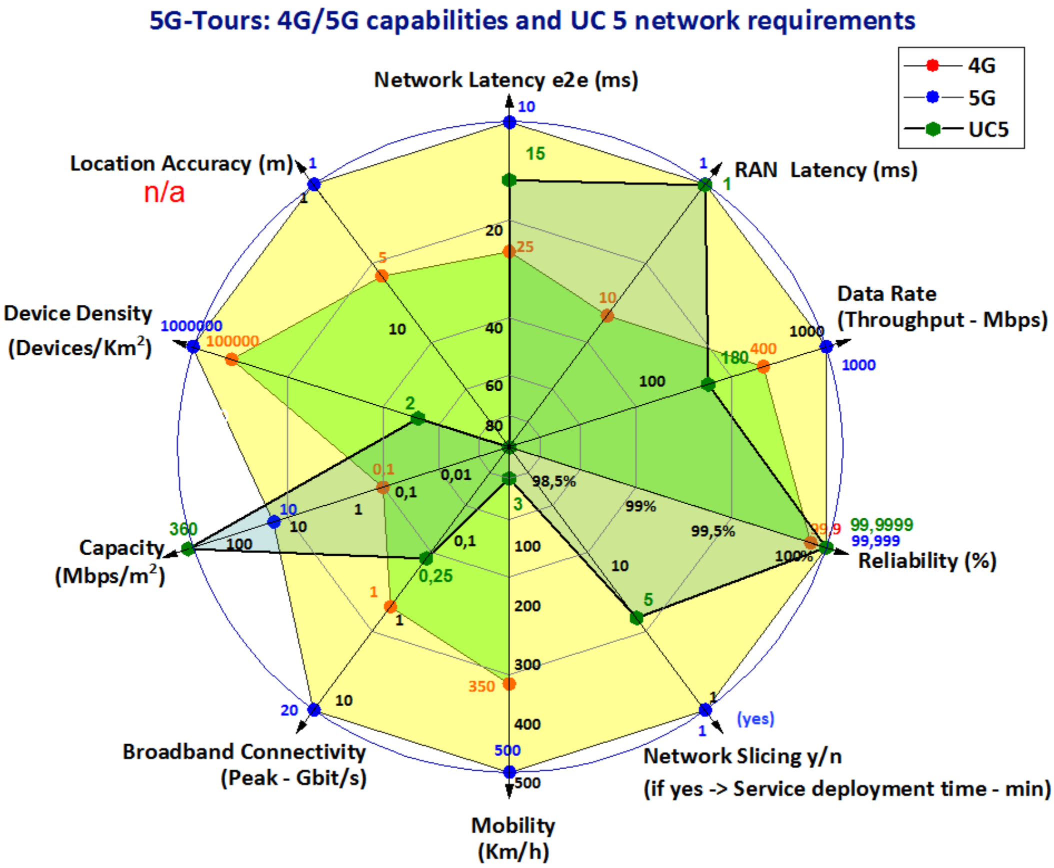

Figure 45 – 4G/5G capabilities and UC5 network requirements

5 Time plan and evaluation methodology

5.1 Milestones description

Table 15 - Trials summary time plan provides the time schedule of the use cases implementation in terms of milestones.

	2019		2020				2021				2022	
	Q1 Y1	Q2 Y1	Q3 Y1	Q4 Y1	Q1 Y2	Q2 Y2	Q3 Y2	Q4 Y2	Q1 Y3	Q2 Y3	Q3 Y3	Q4 Y3
UC1			M1			M2	M3			M4,M5		M6
UC2		M1		M2,M3		M4	M5	M6			M7	
UC3				M1		M2	M3	M4			M5	
UC4			M1			M2	M3			M4		
UC5			M1		M2	M3		M4,M5		M6		

Table 15 – Trials summary time plan

<u>Use case 1 Milestone description</u>

UC1, M1: Design activity

- Definition of the storytelling, identification of existing contents and production of new ones
- Requirements gathering
- Architecture design activity
- Target: January 2020

UC1, M2: solution implementation phase 1

- Alpha release delivery
- Target: September 2020

UC1, M3: solution implementation phase 2

- Beta release delivery
- Target: January 2021

UC1, M4: solution implementation phase 3

- Candidate release delivery
- Target: September 2021

UC1, M5: Release candidate Trial

- Trial with candidate release
- Target: September 2021

UC1, M6: Final Validation

- Experiment assessment and final evaluation
- Target: March 2022

<u>Use case 2 Milestone description</u>

UC2, M1: use case, technical and application requirement defined

- Definition of the application/technical requirements of three sub-use cases
- Target: September 2019

UC2, M2: application development, robots and system integration

- Application development will proceed in parallel for different sub-use cases
- Robot and system integration will be based on the API provided by robot manufacturer
- Target: March 2020

UC2, M3: Double robot solution deployment

- Double Robot and system integration of robots will be based on the API provided by the robot manufacturer
- Target: May 2020

UC2, M4: Double robot trial monitoring and final evaluation

- Trial monitoring and final evaluation of Double robot
- Target: November 2020

UC2, M5: R1 robot solution deployment and first trials

- R1 robot in TOR using 5G connectivity.
- Target: December 2020

UC2, M6: R1 robot testing in real condition

- R1 solution testing in TOR in real conditions using 5G connectivity
- Target: May 2021

UC2, M7: R1 robot final validation

- Robot testing in TOR in real conditions using 5G connectivity
- Target: December 2021

Use case 3 Milestone description

UC3, M1: use cases and technical requirements defined

- Definition of the guided tour path, user interaction and robot dialog
- Target: April 2020

UC3, M2: use case development

- Application SW development and validation in Laboratory
- Target: November 2020

UC3, M3: Beta test of application

- First test with the robot in TOR using 5G connectivity
- Target: December 2020

UC3, M4: Test of application in real condition

- Robot testing in TOR in real conditions using 5G connectivity
- Target: May 2021

UC3, M5: Final validation

- Robot testing in TOR in real conditions using 5G connectivity
- Target: December 2021

Use case 4 Milestone description

UC4, M1: use cases and technical requirements defined

- Technical requirements definition
- Target: February 2020

UC4, M2: LTE-broadcast implemented

- The NSA 5G network of ERI-IT incorporates the implementation of LTE-broadcast capabilities in the RAN
- Target: November 2020

UC4, M3: phase-1 trials completed

- The first phase of the trials is successfully completed using ERI-IT's NSA 5G network with LTE-Broadcast RAN capabilities. The first phase of the trials is successfully completed using RAI's broadcasting network with enTV Rel-14 capabilities
- Target: February 2021

UC4, M4: phase-2 trials completed

- The second phase of the trials is successfully completed using a 5G network with unicast/broadcast switching capabilities. enTV Rel-16 is implemented. The second phase of the trials is successfully completed
- Target: November 2021

Use case 5 Milestone description

UC5, M1: Design and technical definitions

- Technical requirements and specifications document
- Target: January 2020

UC5, M2: First round of development, system integration and preliminary functional test

- First prototype implementation of portable 5G camera transmission system (backpack) and functional tests
- Target: June 2020

UC5, M3: First on-site trial and functional test

- Technical on-site tests to demonstrate the fulfilment of the requirements
- Target: September 2020

UC5, M4: Second round of development

- Full prototype implementation of backpack and remote control room
- Target: March 2021

UC5, M5: Second on-site trial with musicians

- Technical and operational test involving a small ensemble to demonstrate the feasibility and sustainability of a real public performance
- Target: April 2021

UC5, M6: Final trial, Main Event

- Final trial including a public performance of the itinerant orchestra
- Target: November 2021

5.2 Trials evaluation methodology

The evaluation of the success of the use cases involves a complex interaction of the verification of the technical requirements and the validation of the final use cases. While the final evaluation methodology followed by the project will be defined in WP7 in its forthcoming deliverables, in this section the discussion is about the input variables and the output metrics that will be considered for the evaluation methodology.

5.2.1 Verification of the technical KPIs.

All the use cases listed in this document present very specific requirements in terms of maximum latency, minimum throughput or area capacity. All of these KPIs are currently listed by relevant fora such as the 5G Public Private Partnership (5G PPP) as the main metrics that have to be evaluated.
In fact, 5G-EVE provides a thorough testing methodology that takes detailed information about relevant metrics as input, such as the network topology, the number of devices or the configuration of the radio access to deliver compelling results in terms of e.g., the experienced delay, the available throughput or higher-level indicators such as the service creation time.
While the testing methodology provided by 5G-EVE targets network KPIs in a NSA mode, the verification methodology put in place by 5G-TOURS for the evaluation methodology shall necessarily be extended to take into account the additional requirements that are imposed to the network. For instance, the one envisioned for the touristic city enhanced use cases also needs to involve more heterogeneous inputs such as the kind of devices (e.g. robots) or their mobility (e.g. for the case of the orchestra). All these new metrics will be used to devise a KPI evaluation methodology that extends the one introduced by 5G-EVE to take into account the 5G-TOURS specificity.

5.2.2 Validation of the services.

Besides the verification of the technical KPIs (i.e., if the network can provide a certain KPI needed by the service) the extent of the use cases proposed by 5G-TOURS in the touristic city and the other trials also imposes the validation of the services from very different viewpoints: technical, business and societal. By leveraging on the KPIs verification activities described above, the 5G-TOURS partners will evaluate the impact of the proposed use cases by adopting methodologies that aim to get feedback from the relevant stakeholder. For instance, the participation in relevant innovation fora for the smart-city or the direct discussion (through detailed questionnaires) with the end-users of the technology may be a possible path to follow in this activity. The detailed methodology will be discussed in close cooperation with WP7 and WP8.

6 Conclusions

In the D4.1 deliverable, "Robotic, media and Smart Cities solutions for Touristic Cities", we discuss the deployment of the touristic city use cases hosted in the Turin node with the aim to enhanced museum visits, interaction with robots, broadcasting of media contents.

The document interacts strictly, on several levels, with almost all the WPs of the project in defining use cases, selecting the suitable technologies, and evaluating the impact on techno-economic plans. As stressed in Section 1, a particular attention was paid to the connection with WP5 and WP6 in order to align the expected activities with the rest of use case trials trying to facilitate inter-networking opportunities. As such, this deliverable includes the following:

- a narrative overview of cultural and tourist offers in Turin, as well as a selection of specific cultural places within which to implement the action,
- a deep analysis and detailed description of use cases,
- an analysis of the available network infrastructure, as well as the required enhancements in order to support the defined use cases,
- a time plan and a trials evaluation methodology definition.

The identified places for the 5G technology trials were chosen in order to provide the most diversified group of museums and cultural offerings within the city, such as: historical museums, modern art galleries, cultural places dedicated to music, innovation poles and urban transformation landmark, educational innovator places, and open-air museum strictly connected to the surrounding environment.

The document implementation, guaranteed by all the partners, has allowed a participatory process in the decision of sites, technologies and development methodologies. It has to be considered as a starting point and reference for the realization of the next project activities. Moreover, the defined trials that will be carried out on different cultural realities, will lead to a proposal of new sustainable cultural tourism by providing transferable and scalable action models to other cities on a national and international level.

Acknowledgment

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Annex A

Palazzo Madama

This area of Palazzo Madama (Figure 46) has significantly changed between the 1600s and the 1800s and could give visitors good idea of the way this Palazzo has changed its role and function.

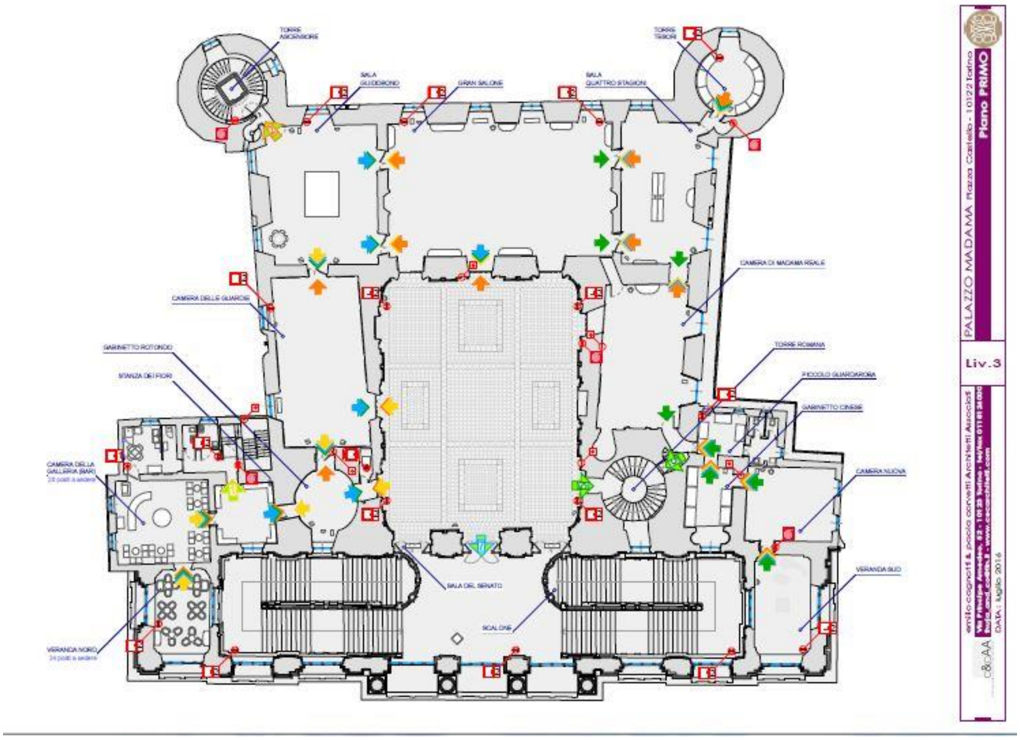

Figure 46 – Plan of Palazzo Madama.

In 1637 the regent for Duke Carlo Emanuele II, Maria Cristina of France, chose Palazzo Madama as her personal residence and commissioned the covering of the court and a revamping of the inner apartments. Sixty years later another regent, Maria Giovanna Battista of Savoy-Nemours, invited many artists to renovate the building which the duchess wanted to turn into a sumptuous royal palace. The artist Domenico Guidobono became the undisputed protagonist of the decorations of the halls on the first floor of Palazzo Madama, known as the Guidobono halls - the Madama Reale’s Chamber, the Chinese Cabinet, and the Southern Veranda. The duchess also asked architect Filippo Juvarra to design a new façade and monumental staircase. In the 19th century Carlo Alberto Charles Albert selected Palazzo Madama as the seat of the royal art gallery, and later, of the Subalpine Senate and of the High Court. Since 1934 it has housed the City Museum of Ancient Art.

Due to the repeated changes in the function of the building from the 1800s onwards, the palace has now remained without the rich furnishing of the apartments, such as paintings, porcelains, furniture, upholstery, musical instruments, etc. The visitor would therefore need to be able to complete the image of magnificence and grandeur that is conferred by the polychrome frescoes, the molded stuccos and the golden reliefs of the windows through a digital instrument that would convey a sense of how these rooms looked like in the Baroque era, with the original decorations that *Madame Reali* envisioned for their residence.

Fondazione Torino Musei has historical records to reconstruct how the rooms of the first floor were furnished, especially the inventory of Palazzo Madama, compiled on the death of Maria Giovanna Battista of Savoy-Nemours. The document bears witness to the splendor of the noble residence, with many pages relating to movable property like upholsteries and fabrics, paintings and musical instruments, furniture and silverware. Through the use of extended reality the current use case should be able to convey visitors a view of the rooms that belonged to the second *Madama Reale* to the visitors, as they were in the past centuries. Thanks to Fondazione Torino Musei inventory, a mock up drawings of some of the rooms on the first floor, and the missing objects will have to be drawn or modeled in 3D so that visitors will be able to see them in a virtual reconstruction of the space, and possibly also interact with the model, being able to move the pieces around or to rotate/analyze sculptures or pieces of furniture modeled in 3D.

Given the historical reconstruction, project partner should model the virtual experience in either one of the following rooms:

1) Madama Reale bedroom: historical reconstruction (Figure 47), today's view (Figure 48)

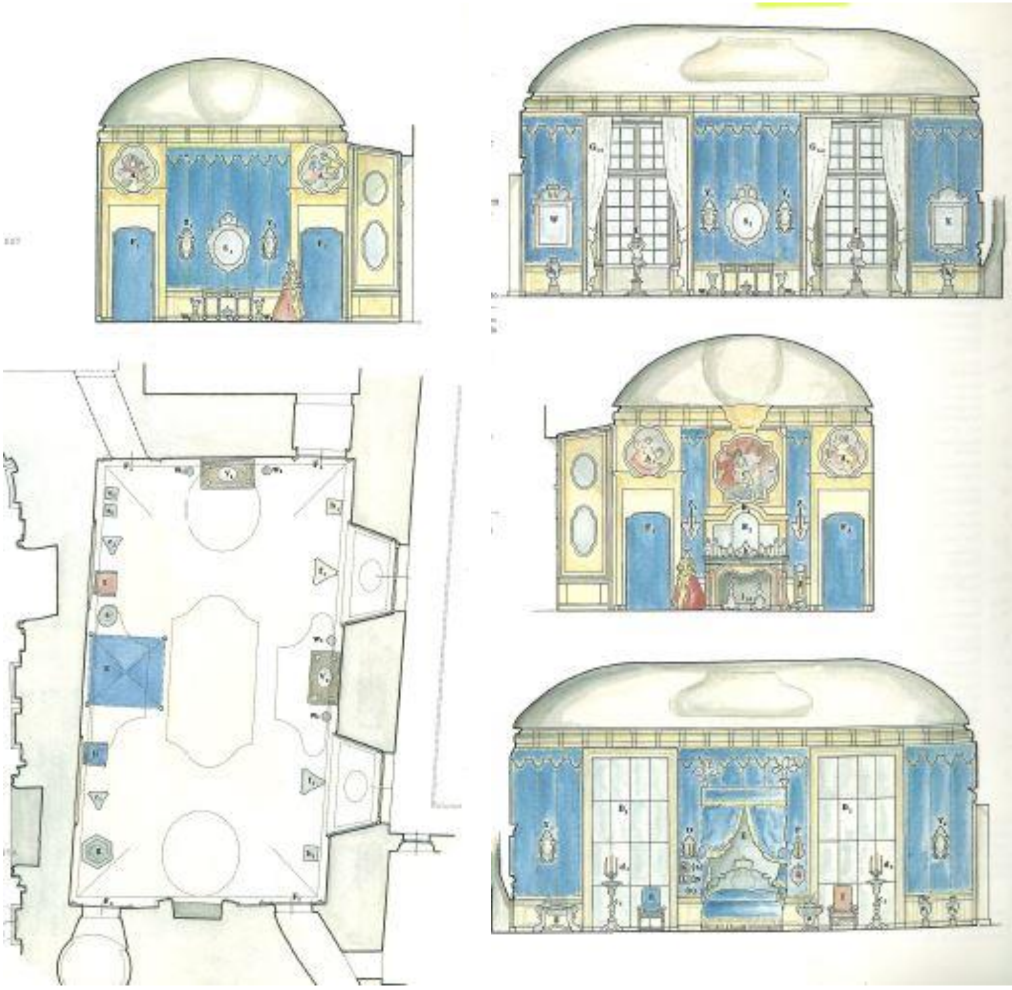

Figure 47 – Historical reconstruction (Madama Reale bedroom)

Figure 48 – Today's view (Madama Reale bedroom)

2) Chinese parlour: historical reconstruction (Figure 49), today's view (Figure 50)

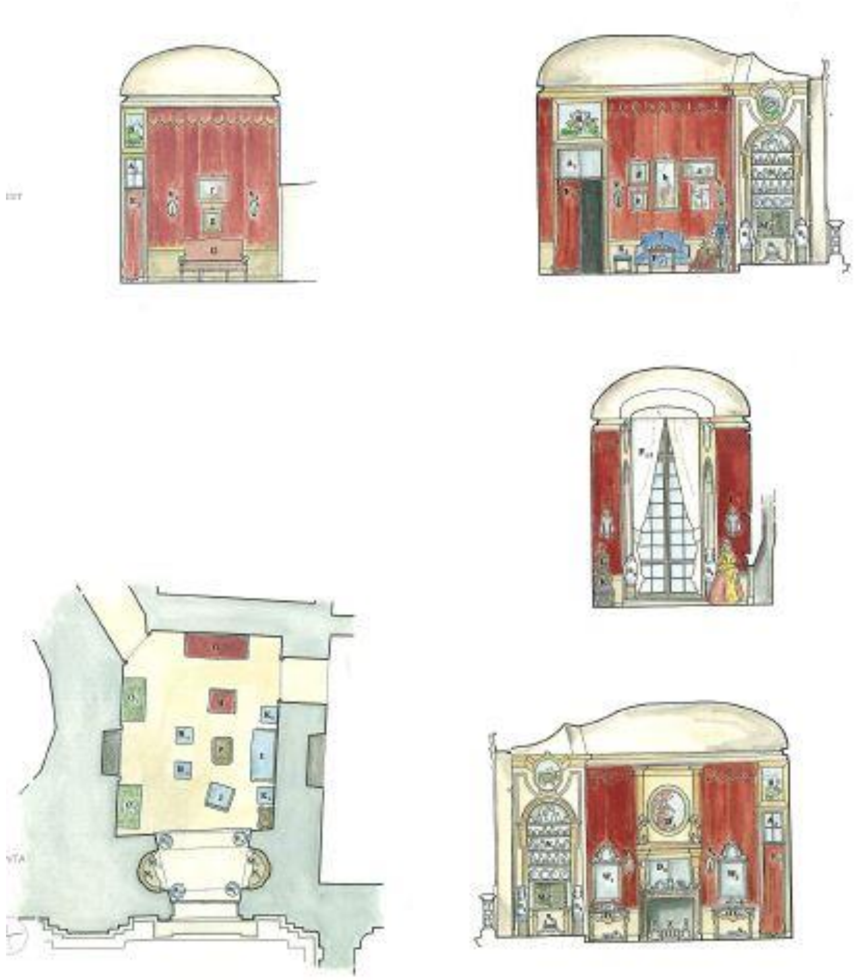

Figure 49 – Historical reconstruction (Chinese parlour)

Figure 50 – Today's view (Chinese parlour)

3) A part of the Salone delle Feste: historical reconstruction (Figure 51), today's view (Figure 52)

Figure 51 – Historical reconstruction (salone delle feste)

Figure 52 – Today's view (salone delle feste)

4) Senate hall: historical reconstruction (Figure 53), today's view (Figure 54)

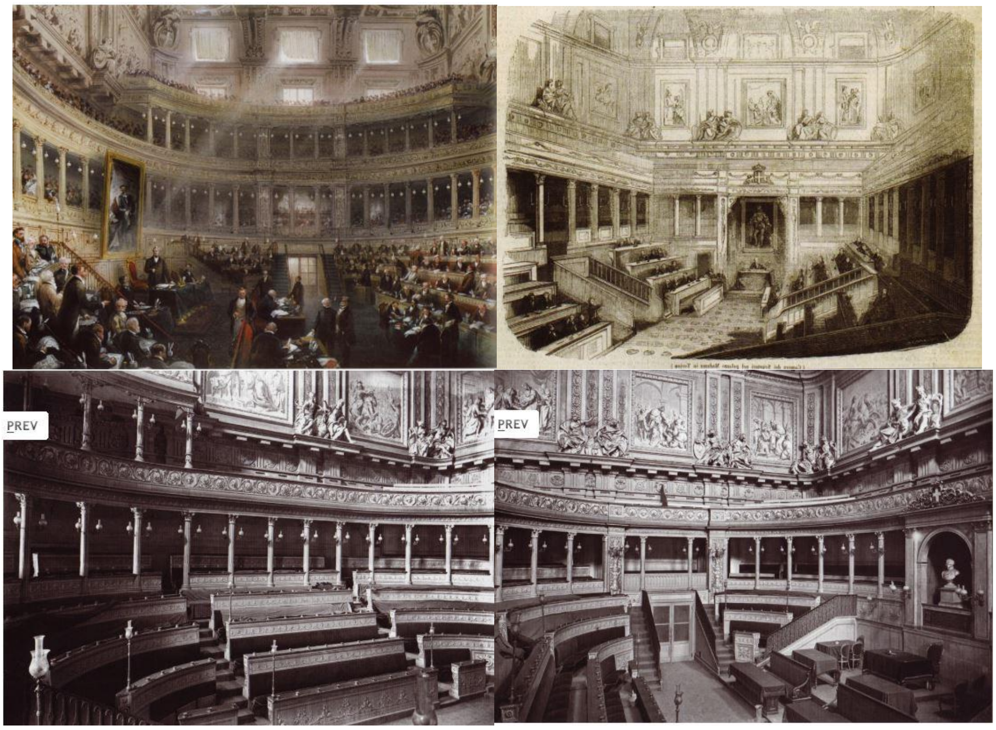

Figure 53 – Historical reconstruction (Senate hall)

Figure 54 – Today's view (Senate hall)

GAM

A section of GAM Education Department will be transformed into a dedicated place where:

- Visitors are surrounded by colored walls.
- Visitors can interact with these images by changing colors, moving elements which constitutes the basis of the painter's poetics (e.g. flowers, stars), combining them in different ways, etc.

- Visitors can easily access to content about the artist.
- Visitors can see where other Nicola De Maria's works are located in the world.

The space (Figure 55) will consist in an entire room of moderate dimensions, that will be:

- accessible to all visitors (it will be accessible by children and wheelchair users),
- easy to use (the way it works should be intuitive),
- used by several people at the same time (even a school group),
- in constant change, using the same technology to provide visitors with a different experience.

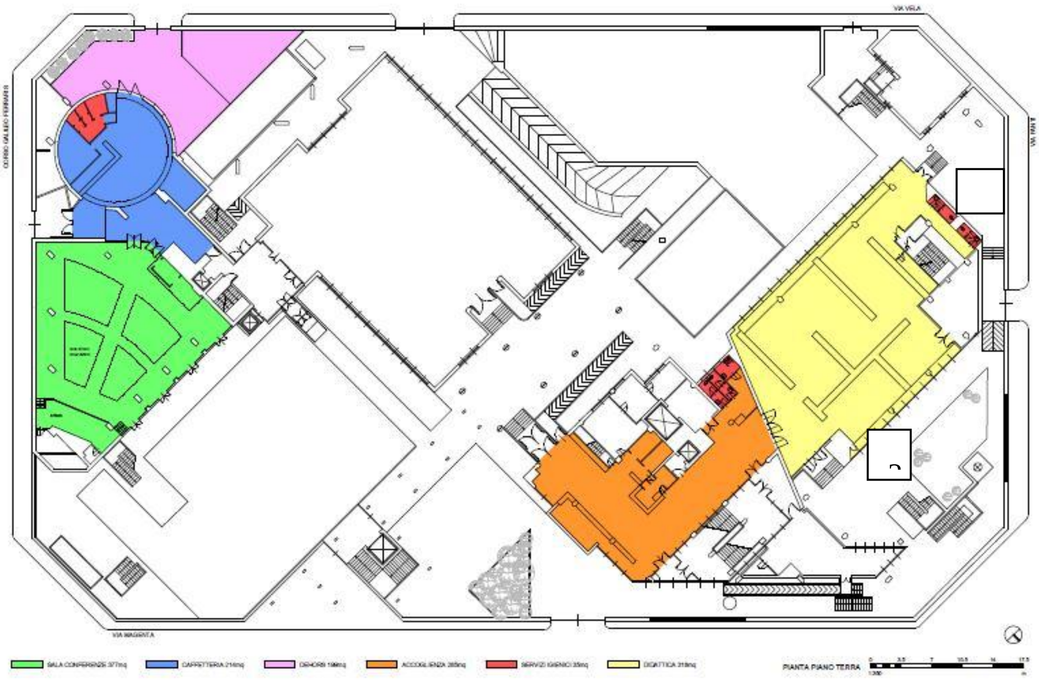

Figure 55 – Map of GAM museum – ground floor.

In the education area of GAM, there are two possible places where immersive canvas can be hosted:

1) Room 1 (Figure 56):
    - The space is connected to a technical room (not accessible to the public, but only by our personnel).
    - Paneled ceiling (so the color effect is lightly spoiled).
    - Can be considered as a "protected" area that is easy to control.

Figure 56 – GAM room 1.

2) Room 2 (Figure 57):
   - This location is immediately visible from the ticket desk. The public can easily access it, but it's more difficult to control
   - Ceiling with spotlights

Figure 57 – GAM room 2.