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The Internet of Things supporting the Cultural Heritage domain: analysis, design and implementation of a smart framework enhancing the smartness of cultural spaces

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Declaration of Authorship

I, Dr. Francesco Piccialli, declare that this thesis titled, 'The Internet of Things supporting the Cultural Heritage domain: analysis, design and implementation of a smart framework enhancing the smartness of cultural spaces' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
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- I have acknowledged all main sources of help.
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Signed: ______________________________

Date: ______________________________

"Two things fill the mind with ever-increasing wonder and awe, the more often and the more intensely the mind of thought is drawn to them: the starry heavens above me and the moral law within me."

Immanuel Kant, *Critique of Practical Reason.*

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
Dipartimento di Matematica e Applicazioni "Renato Caccioppoli"

Abstract

Scienze Computazionali e Informatiche - XXVIII Ciclo

Doctor of Philosophy

The Internet of Things supporting the Cultural Heritage domain: analysis, design and implementation of a smart framework enhancing the smartness of cultural spaces

by Dr. Francesco PICCIALLI

Nowadays embedded systems have reached a great level of maturity and diffusion thanks to their small size, low power consumption, large connectivity and variety of application in everyday contexts. These systems, if properly structured and configured, can significantly increase the smartness of the environments where they are deployed, monitoring and continuously collecting data to be processed and elaborated. In this perspective, the Internet of Things (IoT) paradigm supports the transition from a closed world, in which an object is characterized by a descriptor, to an open world, in which objects interact with the surrounding environment, because they have become "intelligent". Accordingly, not only people will be connected to the internet, but objects such as cars, fridges, televisions, water management systems, buildings, monuments and so on will be connected as well. The Cultural Heritage represents a worldwide resource of inestimable value, attracting millions of visitors every year to monuments, museums and art exhibitions. Fundamental aspects of this resource to be investigated are its promotion and people enjoyment. Indeed, to achieve an enjoyment of a cultural space that is attractive and sustainable, it is necessary to realize ubiquitous and multimedia solutions for users' interaction to enrich their visiting experience and improve the knowledge transmission process of a cultural site. The main target of this PhD Thesis is the study of the IoT paradigm, devoted to the design of a smart framework supporting the fruition, enjoyment and tutelage of the Cultural Heritage domain. In order to assess the proposed approach, a real case study is presented and discussed. In detail, it represents the deployment of our framework during an art exhibition, named *The Beauty or the Truth* within the Monumental Complex of San Domenico Maggiore, Naples (Italy). Following

the Internet of Things paradigm, the proposed intelligent framework relies on the integration of a Sensor Network of Smart Objects with Wi-Fi and Bluetooth Low Energy technologies to identify, locate and support users. In this way technology can become a mediator between visitors and fruition, an instrument of connection between people, objects, and spaces to create new social, economic and cultural opportunities.

The Thesis is structured as follows. **Chapter** 1 describes the preliminary definitions and the state of the art concerning the Internet of Things paradigm. **Chapter** 2 reports the analysis and definition of a smart cultural environment, the managing of the context and a complete overview of ICT methodologies within such domain, while **Chapter** 3 reports the design and implementation of an intelligent IoT framework supporting the Cultural Heritage domain. Finally, **Chapter** 4 presents a case study in order to validate and assess the proposed approach.

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I wish to express my sincere thanks to all those who have guided, inspired and supported me: the list is quite long, but I hope I will not forget anyone.

Foremost, I would like to express my sincere gratitude to my advisor and tutor Prof. Angelo Chianese for the continuous support of my Ph.D study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Ph.D study.

Besides my tutor, I wish to express my sincere thanks to my tutor, Prof. Isabella Valente, for helping me during my Ph.D. experiences, especially for what concern my approach to the Cultural Heritage domain.

I would like to thank those who have always believed in me, in my work, and in my academic career, assisting me, with love, in every moment with words of comfort and reassurance.

I wish to express my sincere thanks to my colleagues who have been my travelling companions and with whom I have shared many experiences and emotions.

Thanks to my wife, in the course of this long period of study and work were close to me, always believing in the realization of this objective.

Finally, thanks to my family, for having made the greatest effort and for supporting me in every moment of my study career.

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To those who have always believed in me

Chapter 1

Introduction to the Internet of Things paradigm

1.1 The Internet ot Things (IoT)

The term Internet of Things was first documented by British visionary Kevin Ashton in 1999. He used the phrase to describe a system where the Internet connects to the "real world" via a ubiquitous network of data sensors. Of course, the use of this term has grown somewhat beyond the original intention, and today it means many things to many people. But to get back to the root of it all, we should also consider the Internet itself to understand the full context of the IoT [1]. The Internet of Things (IoT) is a new paradigm that combines aspects and technologies coming from different approaches. Ubiquitous computing, pervasive computing, Internet Protocol, sensing technologies, communication technologies, and embedded devices are merged together in order to form a system where the real and digital worlds meet and are continuously in symbiotic interaction. The smart object is the building block of the IoT vision. By putting intelligence into everyday objects, they are turned into smart objects able not only to collect information from the environment and interact/control the physical world, but also to be interconnected, to each other, through Internet to exchange data and information. The expected huge number of interconnected devices and the significant amount of available data open new opportunities to create services that will bring tangible benefits to the society, environment, economy and individual citizens [2].

IoT refers to an emerging paradigm consisting of a continuum of uniquely addressable things communicating one another to form a worldwide dynamic network. The origin of IoT has been attributed to members of the Auto-ID Center at MIT, the development community of the Radio-Frequency Identification (RFID), around 2000 [3]. Their idea

FIGURE 1.1: The IoT phenomena

was visionary: they aimed at discovering information about a tagged object by browsing an Internet address or a database entry corresponding to a particular RFID. To address the above idea, they worked on the development of the Electronic Product Code (EPC), i.e., a universal identifier that provides a unique identity for every physical object [4], with the aim of spreading the use of RFID in worldwide networks. Today, the concept of thing is more general and is not limited to RFID only. A thing can be any real/physical object (e.g., RFID, sensor, actuator,) but also a virtual/digital entity, which moves in time and space and can be uniquely identified by assigned identification numbers, names and/or location addresses. Therefore, the thing is easily readable, recognizable, locatable, addressable and/or controllable via Internet. Moreover, this new generation of devices is smart thanks to the embedded electronics allowing them to sense, compute, communicate, and integrate seamlessly with the surrounding environment. The association "one device/one function" disappears, but the whole set of objects becomes the place where the function is activated, resulting all widely distributed. The emerging IoT scenario is depicted in Fig. 1.1 [5]. Smart devices will form the so-called sensory swarm and will be the majority of the system. They will be extremely heterogeneous in terms of resource capabilities, lifespan and communication technologies. They will exceed classic devices such as smartphones and tablets, which, on the contrary, will form a way for accessing Internet [6]. At the core, instead of having traditional computation systems, the Cloud will provide the abstraction of a set of computers and will offer computation and storage services. It is envisaged that the number of connected things4 will exceed 7 trillion by 2025 [7], with an estimate of about 1000 devices per person. A part of them will be wearable [8], but the majority will be in the infrastructure. In this vision, humans will be completely immersed in the world of technology.

1.1.1 A brief history of the Internet evolution

It is important to understand the evolution of the Internet before discussing the evolution of context-aware technologies. The Internet broadly evolved in five phases as illustrated in Figure 1.2. The evolution of Internet begins with connecting two computers together and then moved towards creating the World Wide Web by connecting large number of computers together. Mobile-Internet emerged when mobile devices were connected to the Internet. People's identities were added to the Internet via social networks [9]. Finally, the Internet of Things emerged, comprised of everyday objects added to the Internet. During the course of these phases, the application of context-aware communication and computing changed significantly [10]. In the early phase of computer networking when computers were connected to each other in point-to-point fashion, context-aware functionalities were not widely used. Providing help to users based on the context (of the application currently open) was one of the fundamental context-aware interactions provided in early computer applications and operating systems. Another popular use of context is context- aware menus that help users to perform tasks tailored to each situation in a given application. When the Internet came into being, location information started to become critical context information. Location information (retrieved through IP addresses) were used by services offered over the Internet in order to provide location-aware customization to users. Once the mobile devices (phones and tablets) became a popular and integral part of everyday life, context information collected from sensors built-in to the devices (e.g. accelerometer, gravity, gyroscope, GPS, linear accelerometer, and rotation vector, orientation, geomagnetic field, and proximity, and light, pressure, humidity and temperature) were used to provide context-aware functionality. For example, built-in sensors are used to determine user activities, environmental monitoring, health and well-being, location and so on [11]. Over the last few years social networking [12] has become popular and widely used. Context information gathered through social networking services [13] (e.g. Facebook, Myspace, Twitter, and Foursquare) has been fused with the other context information retrieved through mobile devices to build novel context-aware applications such as activity predictions, recommendations, and personal assistance [14]. For example, a mobile application may offer context-aware functionalities by fusing location information retrieved from mobile phones and recent 'likes' retrieved from social media sites to recommend nearby restaurants that a user might like. In the next phase, 'things' were connected to the Internet by creating the IoT paradigm. An example of context-aware functionality provided in the IoT paradigm would be an Internet-connected refrigerator telling users what is inside it, what needs to be purchased or what kind of recipes can be prepared for dinner. When the user leaves the office, the application autonomously does the shopping and guides the user to a particular shopping market so s/he can collect the goods it has purchased.

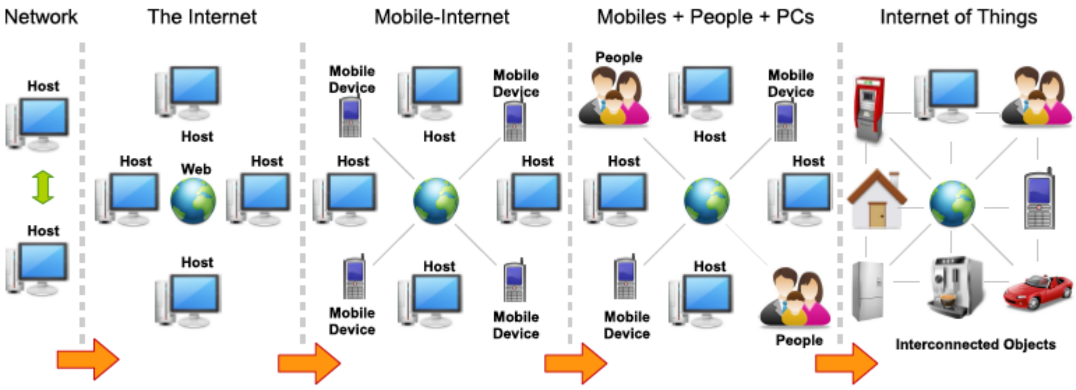

FIGURE 1.2

In order to perform such tasks, the application must fuse location data, user preferences, activity prediction, user schedules, information retrieved through the refrigerator (i.e. shopping list) and many more. In the light of the above examples, it is evident that the complexity of collecting, processing and fusing information has increased over time. The amount of information collected to aid decision- making has also increased significantly.

1.1.2 Different visions for a novel paradigm

The growing interest that scientific research as well as marketing and sales strategies raises onto the IoT paradigm has the inevitable consequence that there is not a clear and unambiguous definition of IoT. This is mainly due to the different underlying visions with which standards organizations and research centers, enterprises and various alliances (each one with a different background and driven by specific interests and purposes) look at this paradigm. The meaning of the term continuously evolves also because technology and the ideas behind it change themselves over time. The term was coined by Kevin Ashton, one of the founders of the original Auto-ID Center at MIT, who introduced it in 1999 during a presentation held at Procter & Gamble (P&G). He imagined a world where Internet is connected to the physical world through ubiquitous sensors and a platform based on real-time feedbacks, which have a huge potential to enhance comfort, security and control of our lives. A few years later, members of the same MIT group used again this concept, defining IoT as: *an intelligent infrastructure linking objects, information and people through the computer networks, and where the RFID technology found the basis for its realization'* [15]. However, only in 2005, when the International Telecommunication Union (ITU) published its first report on the subject, the term "Internet of Things" began official and relevant to researchers, industries and end-users. In [16], ITU explains its vision: *a new dimension has been added to the world of information and communication technologies (ICTs): from anytime, any place* *connectivity for anyone, we will now have connectivity for anything. Connections will multiply and create an entirely new dynamic network of networks – an Internet of Things.* Here the emphasis is on the fact that not only RFIDs, but also a high number of different objects – univocally addressable – constitute the underlying fabric of IoT. From 2005 on, the number of IoT definitions, and the related activities, have run up depending on the type of organization looking at this paradigm. In [17], authors report a number of IoT visions proposed over the past years. Specifically, they distinguish three categories: (i) *Things* oriented, where the focus is on the "objects" and on finding a paradigm able to identify and integrate them, (ii) *Internet* oriented, where the emphasis is on the networking paradigm and on exploiting the IP protocol to establish an efficient connection between devices, while simplifying IP so that it can be used on devices with very limited capacity, and (iii) *Semantic* oriented, which aims to use semantic technologies, describing objects and managing data, to represent, store, interconnect, and manage the huge amount of information provided by the increasing number of IoT objects. Authors conclude that IoT is the result of the convergence of these different visions.

1.1.3 IoT enabling the Smart City paradigm

To make the concept of IoT more concrete, let us consider the city ecosystem as an example and how the city of the future will look like [18]. The city is the economic and social life core of a nation. Today, half of the global population is concentrated in the cities and consume its resources (e.g., light, water) every day. Urban population is constantly growing and this implies an inevitable increase in the resource consumption that undermines the environment. Quality, sustainability and security are crucial and unavoidable issues for the city. The realization of sustainable and secure cities requires intelligent solutions that ensure the efficiency at multiple levels aiming to: (i) a more aware and optimized usage of the offered resources, (ii) a minimization of environmental impact, for example by reducing CO_2 emissions, and (iii) a tangible increase in the life quality in terms of safety, health, and wellness. Indeed, a smart city is a city that operates simultaneously on two levels: one physical and one virtual. The smart city provides a management of its services (e.g., transport, energy, lighting, waste management, entertainment) through the widespread usage of ICT technologies. Such technologies provide a logical/virtual infrastructure that controls and coordinates the physical infrastructure in order to adapt the city services to the actual citizen needs, while reducing waste and making sustainable the city [18]. IoT will be essential to turn a traditional city into a smart city and the traditional and more emerging sectors such as mobility, buildings, energy, living, governance will also benefit of it. For example, smart mobility services will be created to provide effective tools to the citizens to accurately plan their journeys with public/private transportations, bike/car/van sharing services or multi- modal transport systems. Intelligent traffic lights and static/mobile sensors spread in the city can be used to automatically manage the traffic, to monitor/predict situations of traffic jam and to warn drivers about the presence of critical situations, also proposing them alternative routes/means in real time. At the same time, data gathered by sensors [19, 20] will help municipalities to monitor the condition of the roads (e.g., presence of potholes, slippery, not draining roads), to plan the waste collection service (e.g., volumetric sensors may measure filling level of trash cans and report to sanitation headquarters when full/close to full), to perform environmental monitoring and territorial prevention by measuring water level, air pollution, presence of a certain component (i.e., percentage of allergenic pollen or radiation in the air) [21]. Energy management will also be optimized by using a smart grid for monitoring and modify consumes in town and buildings through actuators and by using renewable energies for the production [22–25]]. Fig. 1.3 provides a schematic representation of the smart city. It will be equipped with a network of sensors, cameras, screens, speakers, smart meters, and thermostats that will collect information. The gathered information, the so-called "Big Data" (the name refers to its large volume and its heterogeneity in terms of content and data representation), will not be used for the improvement of just a single service/application, but it will be shared among different services [3]. To this aim, a common platform for operational management of the city – a sort of City Operating System – will be responsible for managing, storing, analysing, processing, and for- warding it where needed within the city to improve services and adapting to human needs. This management layer, no longer vertical but horizontal, will ensure interoperability, coordination, and optimization of individual services/applications through the analysis of information flows. Citizens/authorities will access the services offered by the platform through their applications, will consume them and will actively participate by creating additional content that will be provided as further input to the City Operating System.

1.1.4 IoT application domains

The IoT is rapidly expanding in many application domains 1.4. Some of these domains are traditionally connected domains, but many other domains were traditionally not connected and are gradually discovering the benefits of interconnectivity. Following are some sample IoT application domains along with a few sample usages.

Building automation/Smart home is the automatic centralized control of a building's Heating, Ventilating, and Air Conditioning (HVAC), lighting, window blinds and other systems through a Building Automation System (BAS). The goals of building

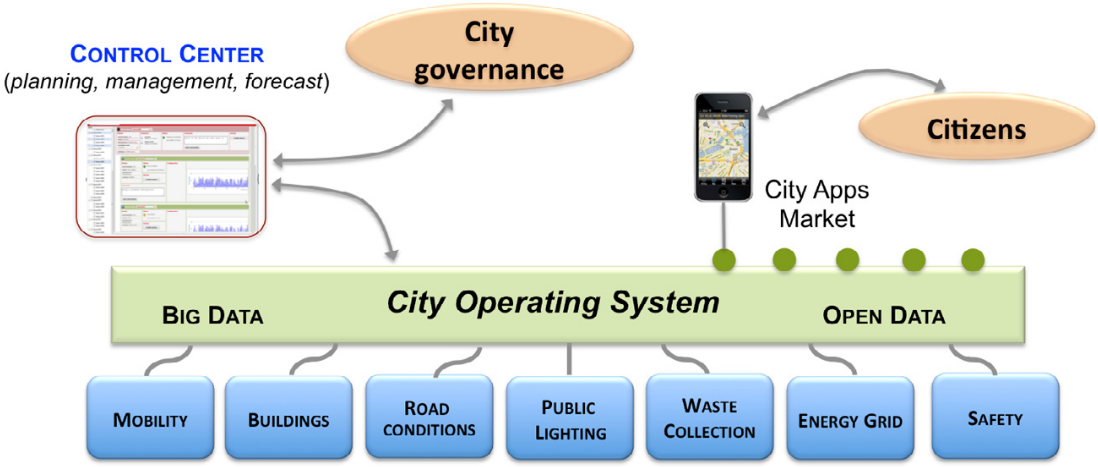

Figure 1.3: A schematic representation for a smart city

automation are to improve the occupants' comfort and at the same time to reduce energy consumption and operating costs through an efficient operation of building systems.

Smart cities use digital technologies to enhance the performance of the city sectors such as transport, energy, health care, water and waste management. The goals are to improve the well-being of the citizens and to engage more effectively and actively with them to reduce costs and resource consumption. It is believed that smart cities will be able to respond faster to challenges than traditional cities.

Health IoT applications are very diverse. One important example is the monitoring of the personal health and fitness by using various sensors typically in the form of wearable devices. These devices can monitor personal activity (e.g., number of steps walked, calories burned, etc.), vitals (heart beat, etc.) and data of more medical relevance such as the blood glucose level. These devices communicate by forming a Wireless Body Area Network (WBAN) and their data can be accessed by smart phones, watches, computers, etc. for further analysis.

Transportation of persons and goods is an important application domain for the IoT, since it is a field that can be optimized to save energy and cost. In 2013, shippers moved more than eight billion tons of cargo around the world [26]. The ability to precisely monitor and track containers is essential for 'just-in-time' delivery, the realization of safe trade lanes and can effectively reduce costs.

Smart metering usually refers to the use of electronic devices to record consumption of various resources (such as electricity, gas and water) and to communicates that information, at least daily, back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the central system and thus can be used for example to disconnect-reconnect the service remotely and thus help to reduce costs. There are 1 billion electricity meters in the world [27] and maybe a similar number of water and other utility meters that will sooner or later be converted to smart meters.

Remote monitoring was initially limited to SCADA (supervisory control and data acquisition) technology and referred to the measurement of disparate devices from a network operations centre and the ability to change the operation of these devices from that central place. Remote monitoring and control is entering a new era with the development of wireless sensors and the IoT. It is being used in many fields such as patient monitoring, smart grid, pipeline sensors, and desktop/server monitoring.

Industrial automation is the use of various control systems for operating equipment with minimal or reduced human intervention. It is believed that this domain is being revolutionized by the IoT [28]. Manufacturing plants are being transformed into flexible ecosystems of reconfigurable production lines that can rearrange themselves to perform any given tasks as efficiently as possible. The IoT is a main enabler of this transformation since it enables industrial machines to offer services, making it possible to use and reuse them in combination with other machines by connecting their respective services.

1.1.5 IoT as a world of *Things*

Looking at the wide range of application domains and their connectivity needs, it becomes obvious that also a wider range of objects will be connected to the IoT to fulfil these needs. The IoT refers to the network of networks of everyday objects, i.e., a network of uniquely addressable interconnected objects. The term Things in the IoT refers to very various objects such as people, devices, clothes, food, books, dogs, etc. Fig. 1.5. These devices have different capabilities and have different communication requirements. Unlike today's Internet, it is expected that the majority of the IoT devices will be resource constrained embedded devices such as sensors and actuators. Sensors collect information about the physical world and inject this information into the virtual world. Next processing and reasoning can occur and decisions can be taken to enact upon the physical world by injecting feedback to actuators.

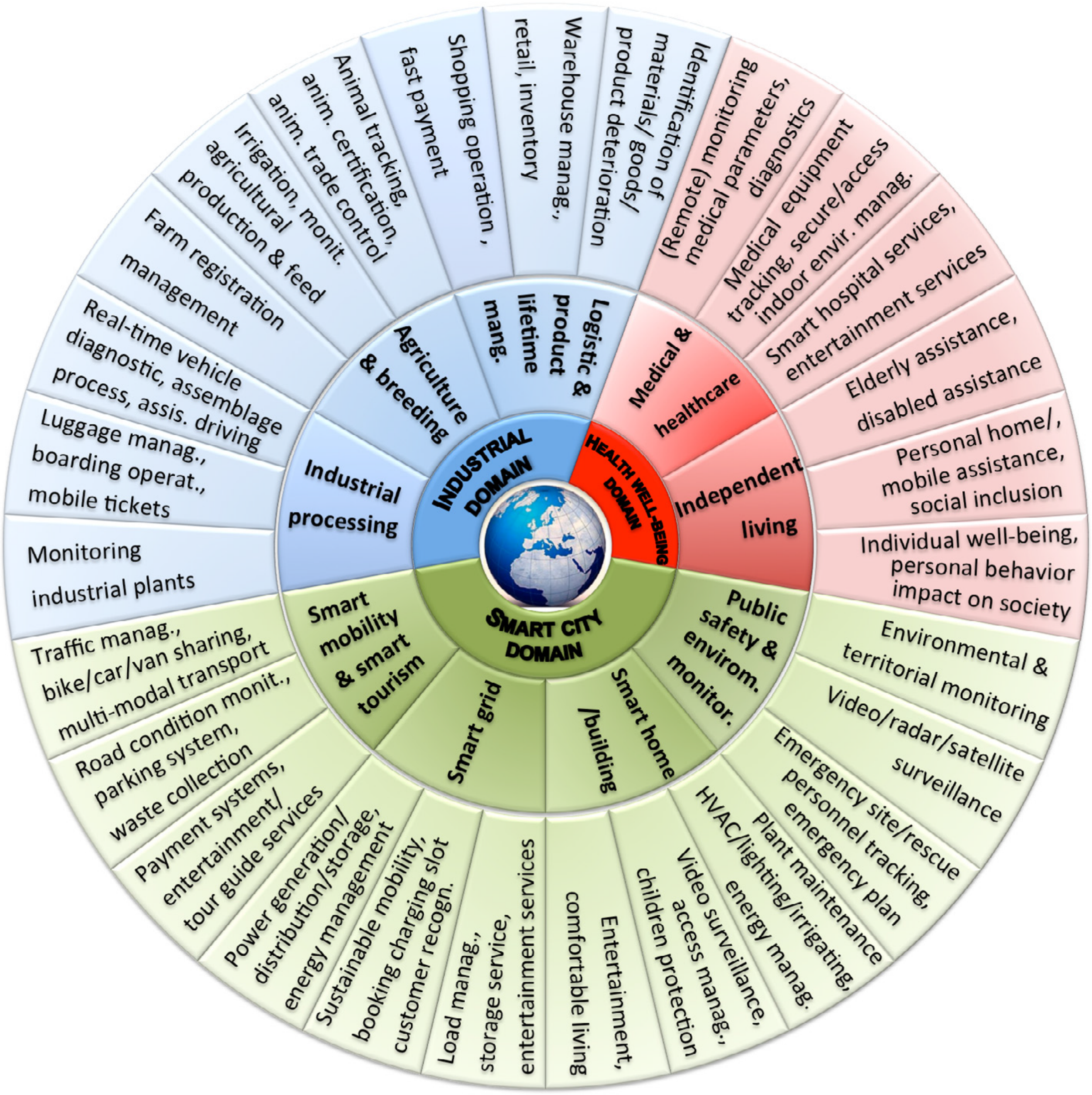

Figure 1.4: IoT application domains

Sensors, actuators and other embedded devices are often optimized for low cost and power consumption and thus have very limited power, memory, and processing resources and have long sleep periods. These resource constrained devices, or just constrained devices for the sake of simplicity, are classified in [29] into three classes:

Class 0 devices are so severely constrained in their resources that most likely they will not be able to communicate directly with the Internet in a secure manner. They will participate in Internet communications with the help of larger devices such as proxies or gateways.

Class 1 devices are quite constrained in their resources, such that they cannot easily employ a full Internet protocol stack. However, they are capable enough to use a protocol stack specifically designed for them. In particular, they have enough resources

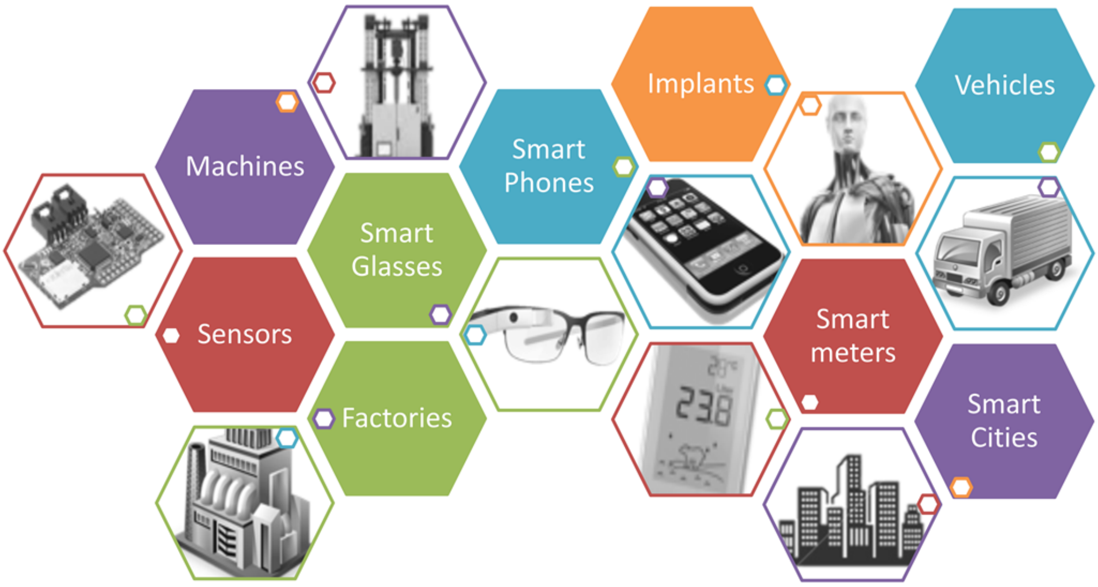

Figure 1.5: IoT devices

to provide support for security functions and thus can be integrated as fully developed peers into the Internet.

Class 2 devices are less constrained and might be capable of employing a full Internet protocol stack. However, since these devices typically need to run some kind of application, reducing the footprint of the Internet protocol stack leaves more resources available to the applications.

1.1.6 IoT network

Sensors and actuators do not operate in isolation, but are connected. They often form their own networks and communicate wirelessly in most cases. Such a net- work is called Wireless Sensor and Actuator Network (WSAN) or just Wireless Sensor Network (WSN) for the sake of simplicity. WSNs are an extension of the current Internet architecture as illustrated in Figure 1.6. WSN are typically connected to the Internet by Gateways (GWs). These gateways have to be able to communicate between the Internet protocol stack and the WSN protocol stack and to translate between them as needed. Similar to the constrained devices that they connect, WSNs are also constrained and have different characteristics than those typical in today's Internet. These constrained networks have high packet loss, low throughput, frequent topology changes and small useful payload sizes. They are referred to as Low-power and Lossy Network (LLN).

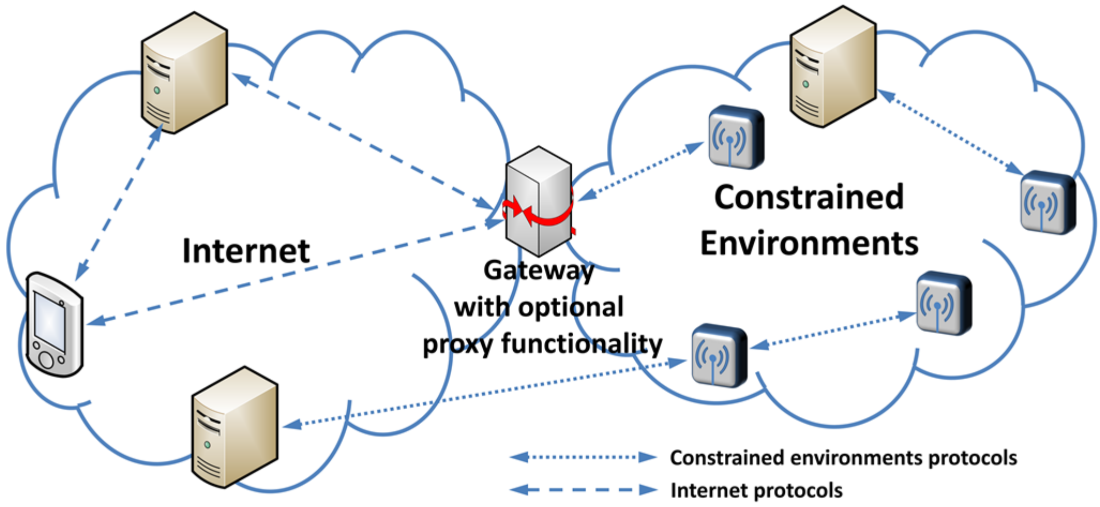

FIGURE 1.6: IoT devices

1.1.7 IoT projects and initiatives

The number of funded projects worldwide aimed at investigating the IoT challenges is rapidly increasing. Starting from 2009 the European Commission launched the IoT initiative within the 7th Framework Programme (FP7) focusing on the development of architectures and optimized technologies for supporting the multitude of novel IoT-based applications and services. This research line continued under the "Internet-connected object" initiative, focused on developing context-aware, reliable, energy-efficient and secure distributed networks of cooperating sensors, actuators and smart devices. A wide range of EU research and application projects have been launched within these two initiatives, supported and coordinated by the European Research Cluster on Internet of Things (IERC). IERC aims at promoting a common vision of the IoT paradigm, facilitating also the knowledge sharing and the secure IoT deployment at world level [30]. The US government started funding projects on IoT almost in the same years. Specifically, four research projects have been funded since 2010 as part of the "National Science Foundation's Future Internet Architecture (NSF FIA)" program, which aims at designing and validating comprehensive new architectures for the next-generation Internet. China, Korea and Japan have also started research programs about IoT. In Korea, only recently the National Research Foundation of Korea (NRF) decided to support projects specifically on IoT. Japanese investments on IoT started when the New Generation Network Promotion Forum (NWGN) was established in 2007. In addition, after the 2011 Tohoku earthquake, the IoT interest converged on specific sectors such as energy saving and renewable energy. As far as China, the focus on IoT has grown considerably since 2009 and it has been supported by several research and development programs, such as: the "National Basic Research Program of China" (973 program), the "National High Technology Research and Development Program of China" (863 program), and the “National Natural Science Foundation of China”. In the remainder of this section, we quickly overview various IoT projects – in progress or already completed – around the world. For the sake of clarity they are grouped in three main categories according to the main objectives (see Fig. 1.7). Interested readers may refer to projects’ website for further information The first group of IoT projects focuses on the development of IoT architectures that ensure interoperability between vertical application solutions and different technologies. A subset of them focuses on business services and on the development of SoA-based architectures and dynamic environments to semantically integrate services into IoT (e.g., EBBITS [31], IoT.est [32]). Another subset focuses on cloud computing architecture to meet the challenges of flexibility, extensibility and economic viability of IoT (e.g., NEBULA [33], BETaaS [34]). Theoretical models of the IoT architecture and the definition of an initial set of key building blocks are key objectives of [35] and IoT-A [36], respectively. Furthermore, the main goal of iCORE [37] and COMPOSE [38] is to develop an open network architecture based on objects’ virtualization that encompasses the technological heterogeneity, while BUTLER [39]] and MobilityFirst [40] aim at developing open architectures providing secure location and context-aware services, transparent inference of users’ behaviors and needs, and actions on their behalf to improve their quality-of-life. The IoT6 project [41] is an example of researching the potentiality of IPv6, and related standards, within a high-scalable SoA-based architecture in order to integrate smart and heterogeneous things and components. The second group of IoT projects deals with the design of innovative communication protocols for IoT. For example, SNAIL [42] proposes a network platform fully compatible with the IETF standards, enabling smart objects to communicate seamlessly one another, while EPCSN [43] aims at developing wireless sensor networks like EPC systems. The ICSI project [44] focuses on Intelligent Transport Systems (ITSs) and proposes intelligent solutions for communication protocols, advanced sensing, and distribution of context-data to enable advanced traffic and travel management strategies. A subset of projects deals with cross-layer communication challenges. For example, CALIPSO [45] focuses on energy efficiency and network lifetime increase by proposing solutions spread at the network, routing and application levels. Conversely, other projects focus on a single network layer, such as GAMBAS [46], OPENIOT [47] and SmartIoT-SSC [48]. Specifically, GAMBAS focuses on open source and adaptive middle-wares for enabling utilization of behavior-driven services, OPENIOT on the dynamic formulation of self-managing cloud environments, and SmartIoTSSC on spontaneous service composition for smart IoT. The last group of projects aims to develop software frameworks that can be directly used and tested by users. This is the case of ELLIOT [49], where users/citizens can test the platform and join in the creation, exploration, experimentation of novel IoT ideas, applications and services. Similarly, Smart Santander [50] focuses on creating an experimental facility for a smart city in order to research and test architectures, key enabling

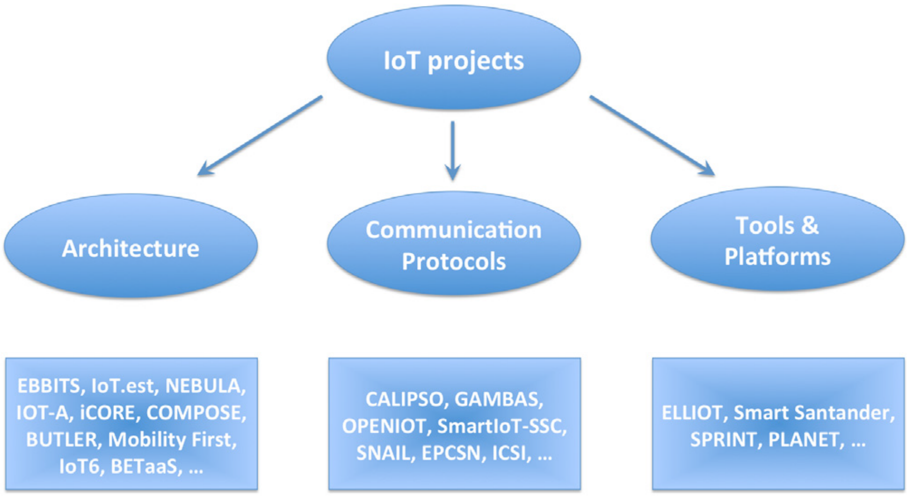

FIGURE 1.7: Taxonomy of IoT projects

technologies, services and applications (e.g., control and management of environmental/ building parameters, of gardens, of parks, of different sensors and mobile devices). SPRINT [51] provides a platform to connect the software tools used by the industrial companies within the project and to allow integration of different sub-systems at the design level. Conversely, the platform developed in PLANET [52] is designed for maintaining and testing heterogeneous and largescale networks, with particular attention to biological reserves and airfield scenarios.

1.2 Research challenges and contributions

Contributions:

- A model of Smart Cultural Environment: the Single Smart Space (S^3);
- An IoT smart framework that relies on:

  A proximity strategy;

  Location-based services;

  A network of Smart Objects;

Challenges:

- Enhancing the cultural experience of people inside these spaces;
- Analysis and preliminary classification of visitors' behaviour using our system;

1.3 Publications

The research results obtained during this PhD research have been published in scientific journals and presented at a series of international conferences. The following list provides an overview of the publications during my PhD research.

1. A. Chianese and **F. Piccialli** A smart system to manage the context evolution in the Cultural Heritage domain, Computers and Electrical Engineering, Elsevier, **DOI:10.1016/j.compeleceng.2016.02.008** IN-PRESS (middle 2016)

2. A. Chianese and **F. Piccialli** SmaCH: an infrastructure for Smart Cultural Heritage environments, International Journal of Ad-Hoc and Ubiquitous Computing, Inderscience, IN-PRESS (late 2016)

3. A. Chianese, F. Marulli, **F. Piccialli** Cultural Heritage and Social Pulse: A semantic approach for CH Sensitivity Discovery in social media data, Tenth IEEE International Conference on Semantic Computing, 2-4 February 2016, California.

4. A. Chianese. P. Benedusi, F. Marulli, **F.piccialli** An Associative Engines Based Approach supporting Collaborative Analytics in the Internet of Cultural Things , Submitted to: Data and Knowledge Engineering, Springer.

5. A. Chianese, **F. Piccialli**, I. Valente The Beauty or the Truth: A Smart exhibition of talking artworks, Submitted to: Digital Creativity, Taylor and Francis.

6. A. Chianese, F. Marulli, **F. Piccialli** A perspective on applications of in-memory and associative approaches supporting Cultural Big Data Analytics , Submitted to: Int. Journal of Computational Science and Engineering, Inderscience

7. A. Chianese, **F. Piccialli**, I. Valente Smart environments and Cultural Heritage: a novel approach to create intelligent cultural spaces, Journal of Location Base Services, Vol. 9 (3), 209-234

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Chapter 2

Intelligent Environments and the Cultural Heritage domain: The *Smartness* as a key factor

2.1 Introduction

The relationship between Cultural Heritage domain and new technologies has always been complex, dialectical and often inspired by the human desire to induce these spaces not created for that purpose, to pursue technological trends, eventually offering to the end-users devices and innovative technologies that could become a "dead weight" during their cultural experiences. However, by means of innovative technological applications and location-based services it is possible to shorten the distance between cultural spaces and their visitors, nowadays determined by the purely aesthetic and essentially passive fruition of cultural objects.

The concept of Smart Environment (SE) identifies a place able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience [53]. Essential conditions are certainly the presence of a widespread connectivity and a digital transformation of communications and services supported by an integrated use of novel technologies.

The adoption of *Future Internet* (FI) technology, and in particular of its most challenging components like the *Internet of Things* (IoT) and *Internet of Services* (IoS), can constitute the basic building blocks to progress towards unified ICT platforms for a variety of applications within the large framework of smart cities [54, 58]. In addition, the recent issues on *participatory sensing*, where everyday mobile devices like smartphones and tablets form interactive and participatory sensor networks enabling public

and professional users to gather, analyse and share local knowledge [59], seems to fit the smartness requirements of an environment in which people have to play an active role.
In the last years, Cultural Heritage has turned out to be one of the most suitable domain in which such achievements can be profitably exploited since it characterizes a domain where different aspects have to be considered at the same time: sustainability of interventions, people enjoyment, promotion and tutelage of spaces and artworks. Many areas of interest of Cultural Heritage can be considered places where people interact with objects capable of arousing interest and excitement because they are offered a direct perception of their knowledge or a combination of perception and knowledge. In this perspective, a cultural space presents a number of features, summarized as follow (see also Figure 2.1:)
(i) an innovative fruition model able to ensure its sustainability, which means the developing of technological platforms, applications and services to safeguard and promote its use, ensuring the enjoyment of cultural offerings (local, distributed, virtual), often distant from the public (the distance resource, experience, individual/group).
(ii) creating diagnostic and monitoring facilities for the environment safeguard, which means developing an integrated system of conservative preservation, through the collection and processing of information (thematic mapping) inherent dynamics and anthropogenic environmental assessments for prior (status, use, instability) of Cultural Heritage.
(iii) a knowledge management framework that is capable of transferring such knowledge to the whole territory, which means designing an integrated system of cognitive safeguard (chronologically catalogued, geo-referenced, tele-discoverable, additive, etc.) of the Cultural Heritage objects and locations that is configurable in flexible mode, interrogated and integrated.

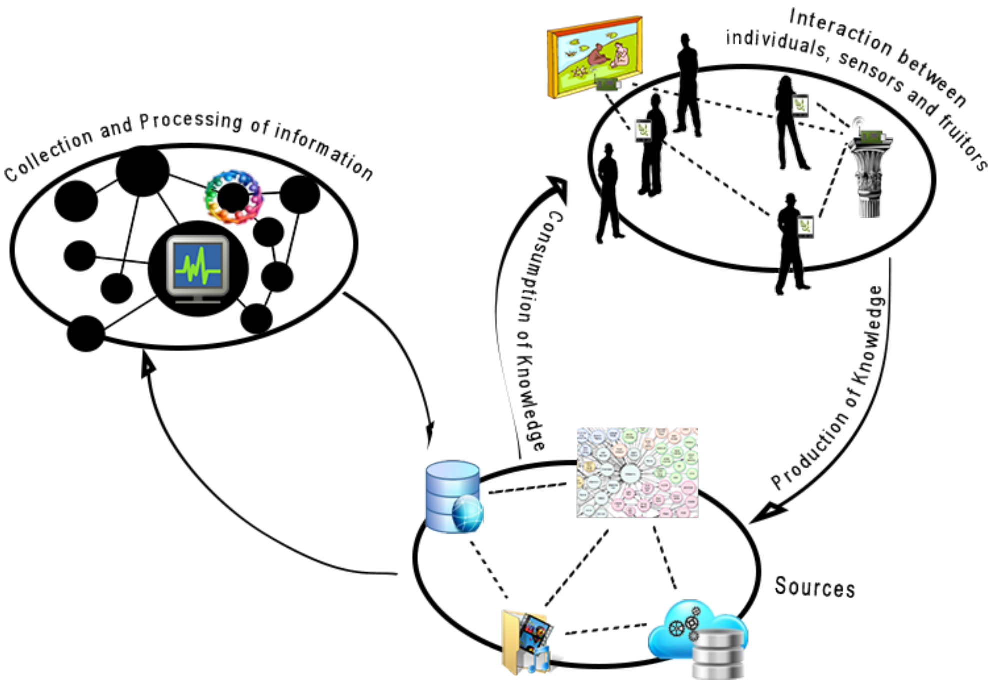

FIGURE 2.1: The needs of an intelligent environment within the Cultural Heritage domain

2.2 Definition of a Single Smart Space S^3

Cultural Heritage represents a world wide resource of inestimable value and such a value gains more and more importance when embedded into the digital ecosystem of a Smart City [55]. In this scenario, persons (citizens, tourists, etc.) and objects (buildings, rooms, artefacts, etc.) equipped with appropriate devices (GPS, smartphone, video cameras, sensors, RFID, etc.) can constitute a particular network in which all the mentioned entities, and more, can communicate and share knowledge. However, the sole application of technological instruments is not enough to effectively define as *smart* a cultural space; exchanged and produced data can be opportunely exploited by a set of applications and services in order to develop such smartness, and from a more general point of view, the entities network can be seen as composed of a set of Single Smart Spaces - S^3 (e.g. indoor museums, archaeological sites, old town centre, buildings, etc..), each needing particular ICT infrastructure.
In the context described above, we define a Single Smart Space, S^3 as a big sensor capable of constantly observing the reality in order to facilitate its transfer into the digital world. A S^3 in its maximum configuration must be able to manage and support:

1. the set of sensors perceiving the real world and providing a vision constantly updated of it,
2. the set of sources (databases, ontologies, log files, etc.) structured and unstructured, which are also useful for the developing of context awareness and multimedia recommendation systems (user profiling/behaviour information, location-based services, multimedia data and visiting paths recommendation, etc.),
3. the environmental monitoring in order to develop reasoning capabilities for interventions based on the produced diagnostics,
4. the individuals that interact within these environments such as companies, public entities, associations, etc.,
5. the end-users as recipients of the actions that ensure the sustainability of the model, both moneywise but also simply as the perceived quality of life,
6. the measurement of intelligence according to the agreed parameters of QI, in order to monitor the effectiveness and efficiency of the actions,
7. the governance of the space, in terms of the possibility of action, aimed at improving the effectiveness and efficiency of interventions,
8. the knowledge produced and adequately stored and classified.

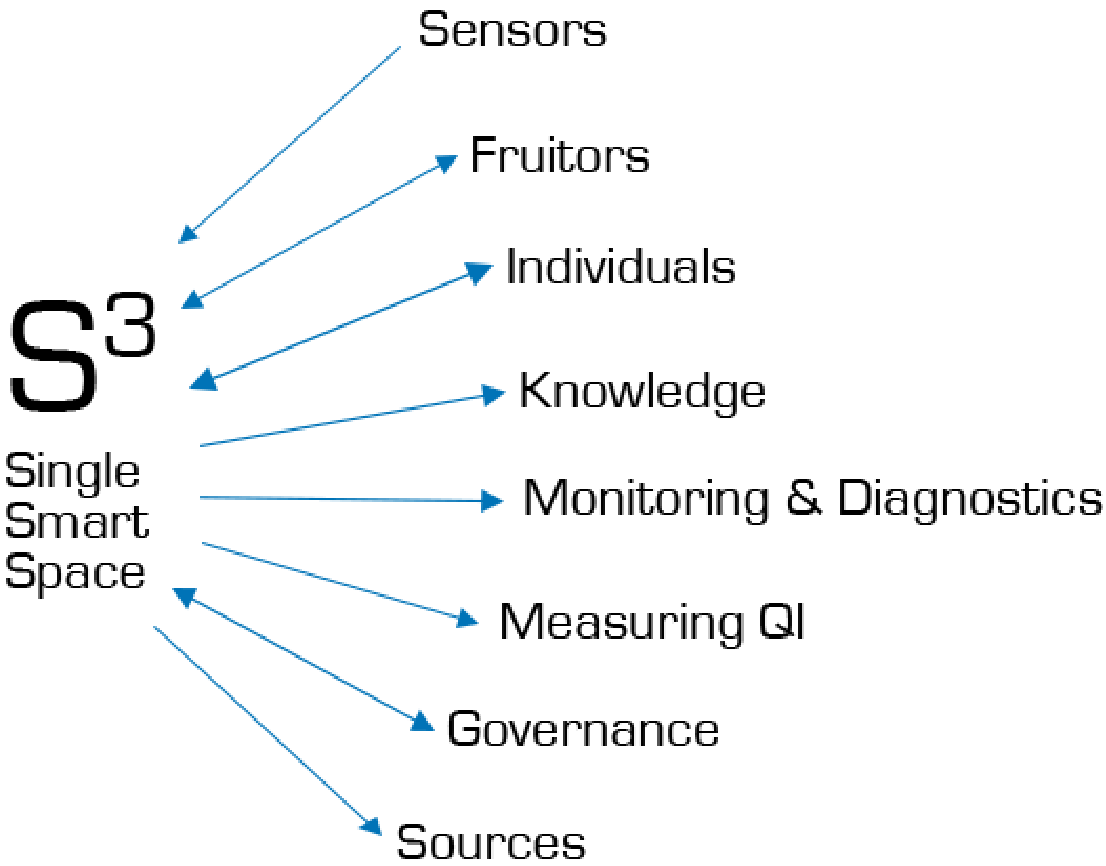

FIGURE 2.2: The Single Smart Space - S^3 model.

Figure 2.2 summarizes the described capabilities of an S^3, by showing the interactions (the arrows indicate the direction in which data passing to and from the S^3) with the created network. The role of technology in a S^3 must be that of a mediator between people, enjoyment and preservation. Accordingly, in our work we design and develop a technological innovative system able to manage and support the listed functionalities of this kind of space. The aim of this kind of space is the developing of such intelligence that is required to transform a static cultural site in an intelligent and dynamic one. The intelligence which we refer is not only addressed to the technological enjoyment of cultural spaces but must be able to accompany visitors during a new cultural and educational experience.

2.3 The role of the Knowledge within a S^3

Clearly, a key role within the process of creating a S^3 is played by the produced and consumed data, since a Single Smart Space constantly provides and is supplied by several flows of information. Such data can be divided into two categories: that produced and consumed one. When we talk about produced data, we refer both to all is regularly captured by technological tools (e.g. sensors, mobile device, web-cam, etc.) placed inside an environment and also to the social data (user opinions, comments, preferences, item ratings, etc.), it can be generated by those who most benefits from the cultural heritage as an active user that can further stimulates the collective desire to live such heritage, triggering social mechanisms of tutelage and preservation (i.e. adoption of a small place/green space, cleaning of streets/squares, etc.) and stimulating more interest in hidden and/or abandoned sites in order to revive them. On the other side, the consumed data are represented by all the information characterizing the end-users fruition and enjoyment processes inside a cultural space (e.g. general information, multimedia content, augmented reality, etc.).
The above described data categories aims to create an integrated knowledge model supporting a S^3, in order to establish a close relationship between the innovative fruition inside such space and the availability of a knowledge base able to sustain the entire process. The knowledge production not only has to align itself with the consolidated need for cataloguing cultural items but must also comply with the following activities:

- Preservation
- Safety
- Tutelage
- Fruition
- Promotion

The production of knowledge takes place through a value-adding chain that starts with the collection of raw data as detailed in Figure 2.3.

In particular the Cultural Heritage fruition should sustain itself with a layered and diversified knowledge representation allowing several configurations based on the end-users characteristics and needs.

Hence, the hub of a S^3 is represented by the knowledge in all its forms, whether it is produced or consumed; in fact, without the existence of such knowledge it would not be possible to trigger mechanisms of enjoyment and preservation. In order to design

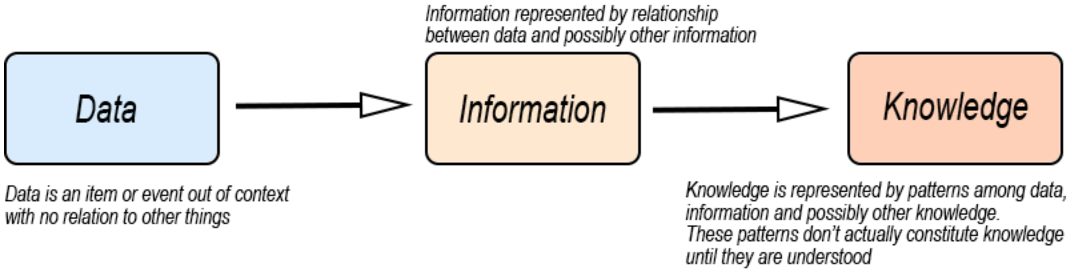

FIGURE 2.3: From data to knowledge.

this knowledge base, it is necessary to take into account several aspects including (i) the storing of multimedia content about cultural spaces and items, (ii) the overall environmental monitored parameters by deployed sensors (temperature, humidity, specific types of gas, people confluence, etc.) and (iii) the users behaviours and feedbacks before, during, and after a cultural experience.

As a first step of this chain, we perform the activity of cultural objects cataloguing that in recent years has been explored and accomplished by numerous administrative entities [1] and European projects [56]; in particular, the district DATABENC fits into this scenario by creating a multimedia artworks' cataloguing through an ad-doc database that complies with the ICCD institute [2] of the Italian Ministry of Cultural Heritage, the formal structure provided by the CIDOC-CRM [3], and oriented to be linkable to the Europeana project [4].

Hence, the focus this activity consists in transforming every kind of reachable (direct and indirect) data into structured knowledge enabling new *polysemic* and enriched ways of fruition. Here, we propose an integrated approach to merge information coming from cultural heritage domain experts, network available datasets (e.g., in form of Linked Open Data), social networks activity data flows and direct interactions between visitors and art sites (context information), under the shape of structured knowledge embodied and named *booklet* entity. Therefore, such entity is the convergence point of well-assessed information (e.g. cultural heritage experts, cultural official datasets), dynamic and social information, dealing with temporal and spatial information and social feelings, perceptions and trends. The booklet is organized to contain not only the artwork identity but also all stages of its life, which can be represented, for example, by phases of restoration, displacements exhibition or catastrophic events incurred. The booklet contents are necessary to feed the artworks fruition and they require a particular structure to ensure that the artworks start to interact with people. Accordingly, a booklet section is dedicated to the stories that the artworks have to tell, in all the modulations used for interaction with

[1] http://www.beniculturali.it/, http://www.campaniacrbc.it
[2] http://www.iccd.beniculturali.it
[3] http://www.cidoc-crm.org
[4] http://www.europeana.eu

its different user classes. In such way, booklet goes further the "simple" role of composite information container, but becomes the crossing gate to select and compose different fruition paths and services, aware of contextual situations and tailored on different kind of users, even suggesting new possible experiences. In the proposed content management approach (see [57] for further details), booklet will be implemented as a software entity collecting composite information. As model to describe atomic information about artworks, we will use the CDWA (Categories for the Description of Works of Arts) [5], a conceptual framework for describing and accessing information about works of art, architecture, other material culture, groups and collections of works, and related images. In particular we will adopt the CDWA Lite, an XML schema to describe core records for works of art and material culture based on the CDWA and CCO [6], and mapping to the Dublin Core [7] metadata element set. Booklet entity is organized in two sections; a first one describing the software object and the main one (Booklet Core), containing artworks properties, structured as collection of instances of CDWA categories.

[5]http://www.getty.edu/research/conducting research/ standards/cdwa/index.html
[6]http://www.vraweb.org/ccoweb/cco/index.html
[7]http://www.dublincore.org/

2.4 Managing the context in a S^3

As mentioned above, a Single Smart Space can opportunely exploit the smartness of a space, through managing the context evolution. Now, we want to represent the evolution of the context that in our hypothesis is driven by *events* corresponding to particular occurring *situations* (e.g. a sensor detects too high a temperature value inside a museum room, etc.) and software *services* (e.g. booking an exhibition visit, using a mobile multimedia guide, etc.). Indeed, the occurrence of situations or the activation of services determines a context-switch and at the same time the dynamic selection of useful data, grouped in (*Contextual Data Views*), and services, grouped in a (*Basket of Services*). These can be opportunely exploited as a result of data and service tailoring. In our case, we adopt a graph structure, named the *Context Evolution Graph* (CEG), able to model the context and its evolution among its instances.
In the following, we formalize the CEG structure. Given a set $C = \{c_1, \ldots, c_n\}$ of contexts, a set $E = \{e_1, \ldots, e_m\}$ of events, a set $S = \{S_1, \ldots, S_k\}$ of baskets of services and a set $V = \{v_1, \ldots, v_h\}$ of contextual data views, we can model the context evolution as a labelled graph $CEG = (C; \Sigma; l_c; l_s)$, where (C, Σ) is a directed graph, $l_c : c \in C \rightarrow (v, S)$ is a function that associates each context with the related contextual data view and basket of services and $l_s : t \in \Sigma \rightarrow e$ is a function that associates each edge in $\Sigma \subseteq C \times C$ with a particular service (or a services composition) that can be activated or a given situation that can occur in the current state, initiating the context-switch. In the case of events corresponding to services' activation, a constraint is generated, in other words the activated services have to belong to the Basket of Services related to the current context
To better understand the proposed approach based on a graph structure modelling the context evolution, we consider a Cultural Heritage scenario, detailing three situations of context evolution managed by the CEG. Consider the first situation, illustrated in Figure 2.4, where an user wants to book a visit to an art exhibition by means of a dedicated mobile app installed on its device.

CASE 1: In the initial state, no useful contextual data are associated to the user; the only available service is the the art exhibition *booking* one. This service allows a visit booking for a particular date requiring some preliminary information about the visitor profile (age, gender, etc.) . Once a visit for a given date has been booked, the switched context instance contains information about the user profile in terms of his/her level of expertise and preferred language and the documentation type (images, video, audio) that will be provided to the mobile application; the *ticketing* service is now available. After the activation of the ticketing service, the user can buy the ticket and download the mobile application.

FIGURE 2.4: Graphical representation of a CEG instance.

CASE 2: Figure 2.5 presents the second situation modeled by the CEG structure, representing a *visitor* inside the art exhibition environment. On the date of the visit, the user can activate the *accounting* service that registers his/her presence inside the exhibition. Consequently, the visitor can start his/her visit and a *proximity_detection* service is now available This service allows the visitor to detect the nearest cultural object, enabling an innovative interaction with this object through multimedia facilities. A *multimedia guide* service will be activated only if the user device, for example, scans a QR-code related to a picture or if a sensor detects its proximity to a cultural item; the user may possibly share images and feedback on social networks about its cultural experience using the *comment* service. During the visit, the user can be accompanied among the exhibited artworks by the multimedia guide service, observing and interacting with the pictures and sculptures. At the end of the visit, the user can terminate the experience by activating the *exit* service and additionally can choose to save his cultural path (observed pictures, multimedia information, etc.) in a digital shape using the *visit saving* service. If during a visit an emergency event occurs, the user has to follow the instructions provided by the *assistant* service (e.g. how to reach the closest exit and/or change the visit path).

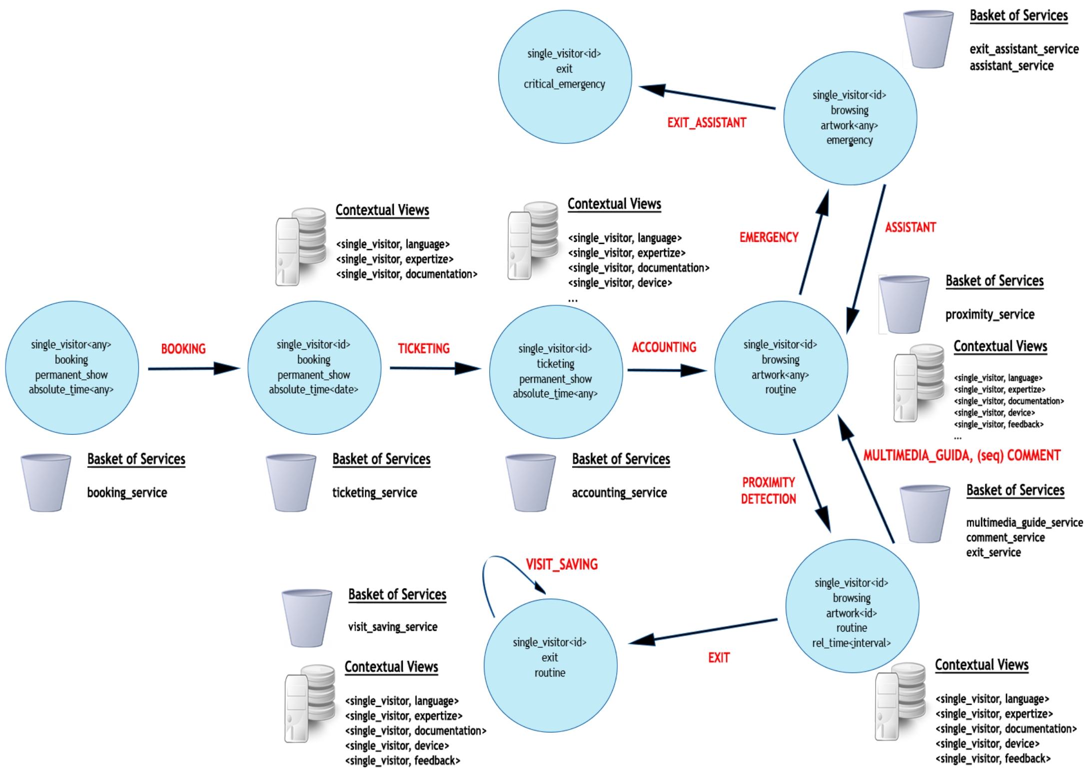

FIGURE 2.5: A part of CEG for a visitor user.

CASE 3: Finally, Figure 2.6 presents the third situation regarding a context evolution modeling during an art exhibition scenario, from a *supervisor user* perspective. At the beginning, the exhibition supervisor can activate the *configuration* service, in order to define the sensors deployment inside the cultural space in terms of type, activation time and location. After this deployment, the supervisor can activate the *monitoring* service that gathers all sensed data. Subsequently, it is possible to activate the *event detection* service in order to analyse the collected data and to detect particular emergency situations or situations requiring particular maintenance activities. In both cases, *recovery* services have to be activated to solve the related problems (e.g. an employee can be informed about the maintenance activities to execute, a critical situations in which all the visitors are encouraged to exit).

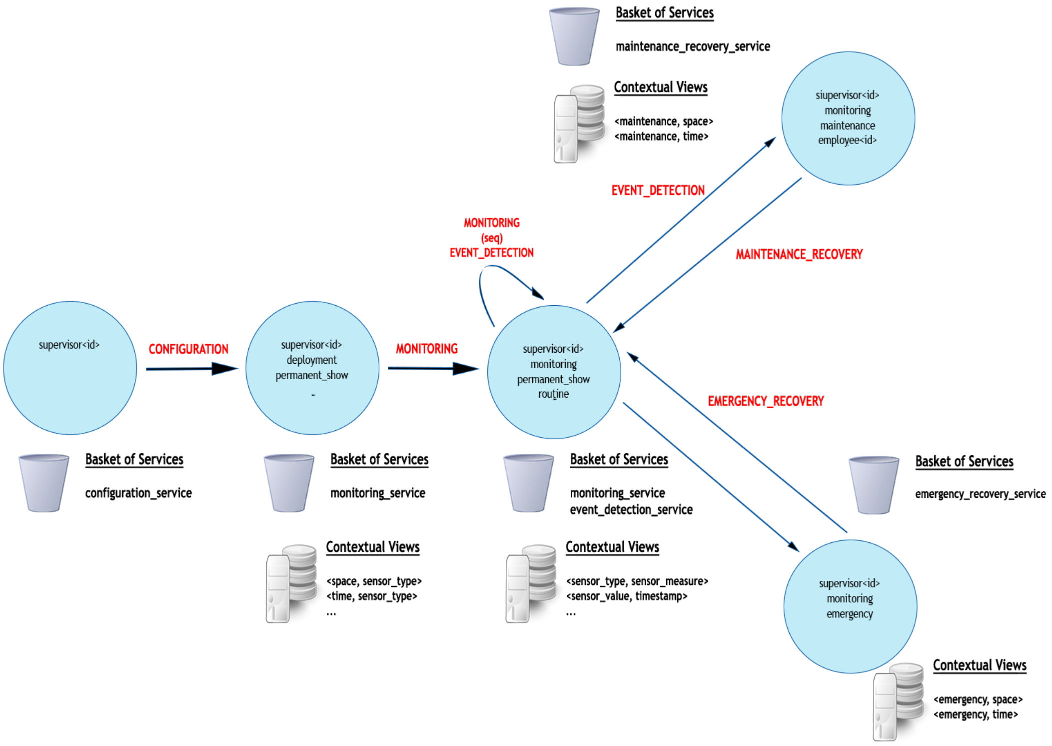

FIGURE 2.6: A part of CEG for a supervisor user.

2.5 Cultural Heritage and ICT methodologies: An overview

2.5.1 Background and motivations

Recent developments in Information and Communication Technologies (ICT) are pushing the definition of new models and patterns for processes and services, supported by the wide diffusion of Wi-Fi, Bluetooth Low Energy (BLE) and NFC technologies, along with new mobile devices, sensors and cheaper applications. The adoption of *Future Internet* (FI) technology, and in particular of its most challenging components like the *Internet of Things* (IoT) and *Internet of Services* (IoS), can constitute the basic building blocks to progress towards unified ICT platforms for a variety of applications within the large framework of *smart cities* [54, 58]. Cultural Heritage has turned out to be one of the most suitable domains in which such achievements can be profitably exploited, since it characterizes a field where several aspects have to be considered at the same time: people enjoyment, sustainability of interventions, knowledge transmission and promotion related to spaces and artworks. Ubiquitous and multimedia computing applied to the Cultural Heritage domain is an emerging discipline which consists of the application of mobile, intelligent and multimedia facilities within cultural sites; it is strongly related to the development of systems able to be pervasive and ubiquitous with the definitive goal of rethinking such spaces. Improving users' experience within a cultural environment and enhancing the knowledge transmission process through ubiquitous and multimedia solutions represents the main purpose of this work. Nowadays, cultural spaces, especially indoor, need more and more support by technological solutions to improve the accessibility, communication and understanding of their collections, establishing from one side a dialogue between the space and the cultural objects, and the visitors from the other one. ICT technologies can characterize a cultural space not as a physical place but as a network of services and applications starting before the visit and ending much later. In this way, a visit itself can be completely re-invented and modelled through modern, dynamic and very engaging enjoyment modalities. In detail, our research efforts have been primarily focused on the design of a service-oriented infrastructure able to easily interoperate with legacy software and databases that could be previously associated to art exhibits or museums. Even though the proposed approach can be easily extended to integrate different low level technologies, in our work we consider a Wireless Sensor Network with Wi-Fi and Bluetooth technologies in order to identify, locate and support visitors through a set of location-based and multimedia services. The technology deployed inside a cultural space assumes the role of mediator between knowledge and people enjoyment, giving visitors the opportunity to easily discover different kind of information, that would otherwise be difficult to access.

2.5.2 The relationship between IoT and intelligent spaces

In the last decade, many ubiquitous and multimedia systems for Cultural Heritage, also trying to adopt the IoT paradigm, have been proposed and discussed. Authors in [86] claim that one of the most recent and interesting applications of pervasive and ubiquitous technology is the provision of advanced information services within public places, such as cultural heritage sites. Accordingly, the design and implementation of systems able to support visitors in cultural environments is a very active and multidisciplinary research field, focusing on several aspects such as the interoperability with legacy museums assets, non-invasive technologies, delivering of personalized multimedia content, usefulness and usability of these technological solutions. As stated by the authors in [91], novel multimedia technologies could be used to design new approaches to the comprehension and fruition of artistic heritage, for example through smart and context-aware artefacts. In this perspective, the IoT paradigm leads to full maturity the concept of *intelligent environment* with numerous applicative effects in everyday life [60, 61]. In the IoT paradigm, devices, as well as cultural objects, exhibition and museum environments can become part of a network of interconnected entities; thanks to this network IoT is able to transform a traditional space in a smart space [71]. The feasibility of IoT derived from the maturity level reached by several enabling technologies such as Wireless Sensor Networks (WSN), Bluetooth Low Energy (BLE), radio frequency identification (RFID) and Near Field Communication (NFC). The WSN have passed through a successful trail of standardization that reached the system IEEE 802.15.4, while RFID-based systems have been successfully applied in logistics scenarios [78].

From the point of view of the interoperability of these systems, it is worth mentioning HERMES [83], which is a distributed middleware following a type and attribute based publish/subscribe model in an event-based architecture; however, rather than concentrating on supporting heterogeneous hardware and on providing low level services to simplify the design of pervasive applications, this work deals with routing algorithms and fault-tolerance mechanisms to develop scalable and robust distributed systems. The authors in [118] propose an infrastructure that aims to allow users to benefit of a uniform and personalized experience across different contexts and spaces. Satoh, in [84] and [85], presents a general-purpose infrastructure to build and manage location-aware applications in ubiquitous computing settings, with the goal of providing people, places, and objects with computational functionalities to support and annotate them.

2.5.3 Cultural Heritage and ICT solutions

In the last decade, some ubiquitous and pervasive systems for Cultural Heritage spaces trying to follow the guidelines of the *Internet of Things* paradigm have been proposed and discussed. As an effort, the use of electronic mobile devices and multimedia facilities inside cultural spaces is widespread [116]; with the ubiquity and diffusion of smart devices, these solutions are significantly increasing. In the following, we discuss several works about the application of technological solutions in the cultural heritage domain. IoT leads to full maturity the concept of *intelligent environment* with numerous applicative effects in everyday life [60, 61]; objects as well as cultural items, buildings, museums and art exhibitions have to become part of a network of interconnected entities and such entities may be considered and be part of an intelligent environment constituting a federated network of intelligent nodes. Several projects and works have been proposed using technological and multimedia facilities to enhance cultural assets since the fruition and promotion of cultural spaces are probably the most interesting and useful applications of these modern technologies. A state of art of the evolution of technology-based personalization in cultural heritage and the current challenges is presented in [116] where the authors provide a comparative exhaustive study that supports the proposed analysis. Among the following works, it is worth mentioning the GAT Platform [81], an interesting solution for fast building and automatic knowledge management of context-aware services for tourism. Supporting our proposal, the authors in [62, 63] stated that technology (i) can play a crucial role in supporting museum visitors and enhancing their overall visit experiences; content and related delivery processes must provide relevant information and at the same time allowing visitors to get the level of detail and the perspectives in which they are interested, (ii) can offer museum professionals new ways of bringing information about their collections directly to their audiences.

In this scenario, mobile systems and applications are certainly areas of ongoing research with large applications to the cultural heritage domain. The application of technological tools within cultural spaces have already been experienced in few recent works [57, 64–70]. In these ongoing projects the authors have presented some initial prototypes aimed to build up smart cultural indoor environments. In this direction, the authors in [73] propose a mobile recommender system for the Web of Data and its application to information needs of visitors in context-aware on-site access to cultural heritage. CRUMPET [111] and GUIDE [112] provide information delivery services for a far more heterogeneous tourist population. In [74] the initial steps of a project aimed at creating mobile apps to facilitate the usability of museum visits for physically disabled and special-needs users are discussed. In [75] a system named SMART VILLA, based on a set of mobile applets each interfaced with a NFC based subsystem and related to particular sites (SMART BIBLIO for ancient books, SMART ROOM for particular rooms and SMART

GARDEN for surrounding historical gardens) is presented. Finally, the authors in [72] present a multimedia mobile guide for the visitors of the Wolfsoniana museum of Genoa; this system aiming to research about Usability and User Experience (UX) of Near Field Communication (NFC) technology applied to the cultural heritage field.
Considering the indoor scenario, the authors in [90] propose a mobile recommender system for the Web of Data and its application to information needs of tourists in context-aware on-site access to cultural heritage. This system, that relies on RFID technology, presents some critical drawback: (i) it can only interact with very old-generation phone, (ii) the visitor has to approach its mobile device to obtain content, consequently only one person at a time can enjoy the cultural item.
For what concerns the outdoor cultural spaces, several projects have been proposed and pioneered by GUIDE [82], which used a Tablet PC to deliver information on points of interest in the city of Lancaster, UK, using cellular WiFi technology for positioning. *MAGA* [114] is an outdoor virtual guide for cultural heritage sites that only assists visitors in their routes at *Parco Archeologico della Valle dei Templi* exploiting speech recognition and location detection techniques. *DALICA* [117] is another agent-based Ambient Intelligence for outdoor cultural-heritage scenarios that is able to send information about nearby points of interest from some fixed sensors. In [126] the authors propose a general architecture of a SNOPS (Social Network of Object and PersonS) Platform presenting a specific smart environment related to the archaeological site of Herculaneum. *CRUMPET* [76] used PDAs for providing dynamic and interactive maps that showed the current position, recommendations, information about attractions, and visiting tips. In this system, positioning was based on GPS data. Finally, the authors in [77] discuss the application of some tutelage technologies and solutions, detailing the existing problems in such scenario.

2.6 Considerations

The Single Smart Space has the purpose to ensure functionalities that are able to guarantee not only an innovative and technologically advanced fruition model, but such technology has to trigger tutelage and monitoring mechanisms within the environments. Nowadays, a limit of traditional cultural spaces is represented by the difficulty to support visitors in the contextualizing of the objects they are observing, in other words, in understanding how and why they are born, the relationship with other surrounding objects, the "geographical" place and the historical epoch of origin. Furthermore, a visitor, when near a cultural object, has very few elements to understand the implications on why it is situated in that space, to interpret all the connections with the historical context in which it is born, to verify under what conditions it evolves with respect to a specific context. In this way, the visitor becomes a passive element inside a static space. In this scenario, the most advanced Information and Communications Technologies (ICT), properly exploited, can significantly improve visitors' requirements; they leave the space's role as binding guardian of the artworks' originality and at the same time provide the network of references, for example, between an artwork, the city and the historical period in which it was produced, the reasons that influenced its creation or the role of this artwork in a specific context. In other words, with a technological intervention, cultural objects can be effectively "dressed" of their context and juxtaposed into it. Accordingly, IoT technologies and multimedia services exploited through mobile devices (e.g. smartphone, tablet) can be applied to satisfy the mobility need of the users, allowing them to access relevant resources in a context-dependent manner.

Chapter 3

An intelligent IoT framework supporting the Cultural Heritage domain: Smart Objects and location-based services

3.1 Introduction

The role of the modern technologies has the purpose to facilitate the integration between digital and real dimensions. Inside a S^3, technologies must be able to connect the physical world with the world of information in order to amplify and share knowledge but also and especially improve the fruition, involving the end-user as an active element which offer the pleasure of perception and the charm of the discovery of new opportunities, collecting information to make more living such space.The development of such technology and advanced services for the Internet of Things (IoT) paradigm is still complicated by the high dynamism of the system, which has to deliver meaningful information to users in real-time, depending on their movements in the physical space, on their interaction with sensors and devices, and accounting for their past choices and current needs.

3.2 The *Smart Cricket*: an IoT intelligent object

Smart Cricket is the name adopted for the prototype sensor boards designed in DATABENC research laboratory to support the entire process of generating, collecting and transmitting knowledge about a cultural sites and items, supporting several functionalities, listed in the section 2.2, to properly manage an S^3. The *Crickets* can be immersed in a cultural space, for example near a cultural object, inside or outside an historical building, a building, a square, etc. with the purpose to facilitate the creation of a smart spaces and objects, by yielding them the ability to *talk*, interact, acquire and transmit knowledge to the people and at the same time monitoring themselves and the environment. Driven by the IoT paradigm, the sensor board to design must be at the same time non-invasive and highly customizable. Therefore, a set of sensors configurable starting from a common core could be the solution to enable the smartness within different cultural sites such as museums, art exhibitions, old town centres, archaeological parks and so on. These boards must not only have the capability to observe the environment in order to characterize, for example, the health status of a cultural item by reporting dangerous situations, the environmental parameters, but must also have the task to protect them from various anthropogenic risks (theft, vandalism). Finally, they must support people fruition and enjoyment establishing multiple connections with the visitors through which convey information, stories and multimedia content.

3.2.1 The Beaglebone Black board

In Databenc research laboratory a prototype set of Smart Crickets, with the aim to cover all the possible contexts of use, has been designed and developed starting from the *BeagleBone Black* Board (BBB), an open hardware product offered by BeagleBone [1]. The choice of this board has been made after a careful analysis; it is a complete open hardware and software product with a very active community that continuously supports developers, also providing several expansion capes. Moreover, the embedded Unix-based operating system allows a full and effective control of the board.
The Beaglebone Black board is a platform distributed by Circuitco [2], the hardware features can be found here [3]. It is an open hardware and software product equipped with an Unix-based OS and presents a big community that supports developers also providing several expansion capes. These capes, designed by the BBB community, are now over 80 for display, motor control, prototyping and power supply, among other functionalities. The arrival of the BBB has heralded a time when a small Linux-powered board can

[1] http://beagleboard.org
[2] http://www.circuitco.com
[3] http://beagleboard.org/Products/BeagleBone+Black

easily, and economically, make sense as a complex sensor or display in the IoT. It also means that developers can end up using web technology that's not suited to the Internet of Things, where the connections may only be occasionally available and as reliable as a cellphone call and where devices need power while sending and receiving information. Figure 3.1 shows all the components (sensor modules) we have used and tested in order to design an intelligent framework composed by different nodes able to (i) sense the environmental parameters like temperature, humidity, gas, ambient light, etc.; (ii) communicate with other entities like people, servers, other nodes, smartphones, thanks to a communication layer that relies on Bluetooth Low Energy and Wi-Fi connectivity; (iii) offer ambient and items safeguard functionalities.

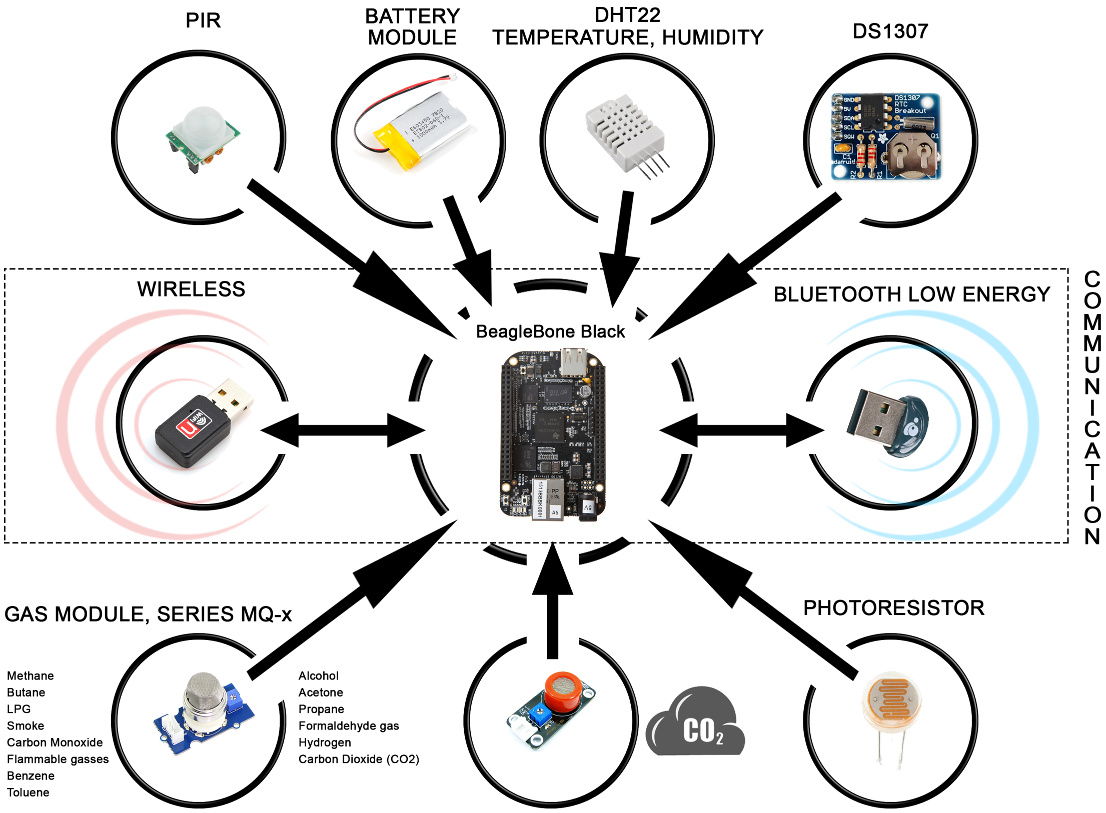

FIGURE 3.1: The BBB with the communication layer and the sensor modules.

3.2.2 Designing a hierarchical network of Smart Objects

The smart network we present can be considered as a hierarchical sensor network composed by multiple nodes, each of them with specific features and functionalities. In the following, each type of sensor node will be detailed. The boards can be configured in different modalities according to the environment (see Figure 3.2).

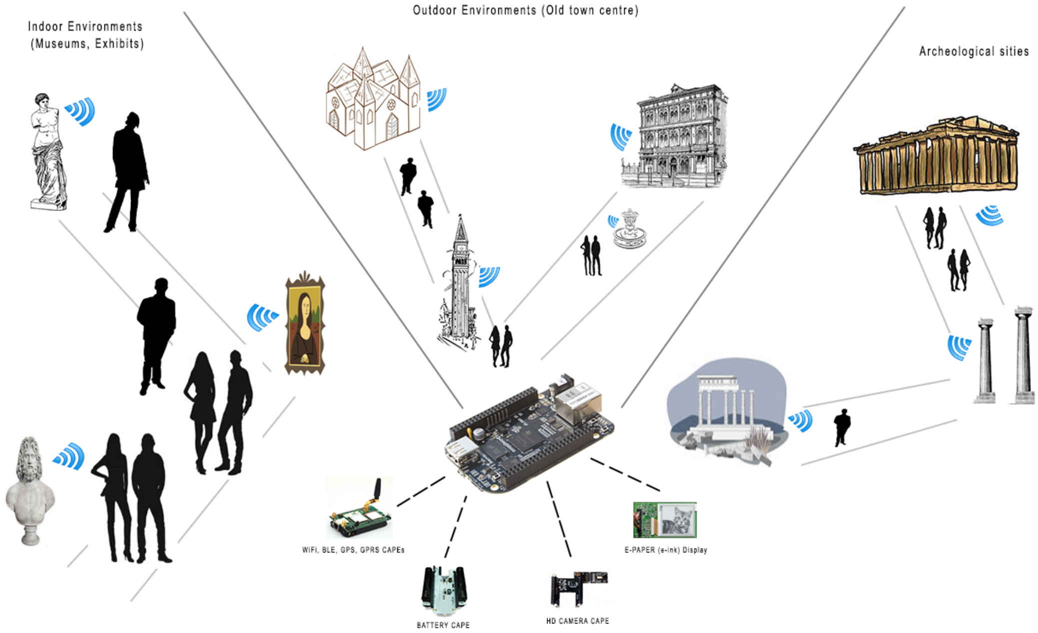

FIGURE 3.2: The environments, both indoor and outdoor, where deploying the Smart Cricket sensors.

- STAND-ALONE: it can be deployed within environments without any kind of connectivity. In this case, the BBB is equipped with a 3G/UMTS cape module. This cape ensures connectivity to the BBB via a telephone operator (with a SIM card installed) and the GPS component provides information about its the geo-referenced coordinates. The data collected by the BBB are sent to a remote platform that captures, stores and supplies data analysis activities.

- CLIENT: in this kind of node the 3G/UMTS module is not installed; the collected data can be viewed via a web application. The node functionalities can be extended with several capes, such as the camera HD, in order to capture and save images and video files for the environmental monitoring. If inside the environment a SERVER and/or MONITOR nodes are installed, the CLIENT will start to communicate and share data with them.

- MONITOR: it is an connector of CLIENT nodes; when in its surrounding area are deployed multiple CLIENT nodes, they can connect to it providing information about the related monitored space. The MONITOR is designed to aggregate the information received from each CLIENT inside the same coverage area, track their activities and report contingent bugs. In addition, this node can be integrated with an LCD cape providing an interface through which the user can check the information held by the node. If inside the area there multiple MONITOR nodes, they can start communication phase sharing the information they hold.

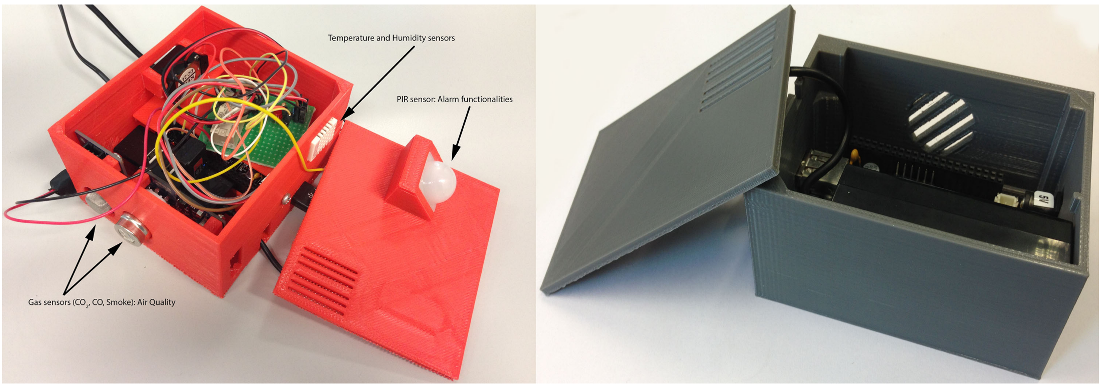

FIGURE 3.3: The Smart Crickets realized with the Beaglebone black board: on the left a Smar Cricket equipped with Humidity, Temperature, Gas, and PIR alarm sensors; on the right a Smart Cricket client node.

- SERVER: it can be considered as a connector of MONITOR and the basic features are the same. In addition, the main task of this kind of node is to oversee the activities of the other nodes; the information retrieved by MONITOR and CLIENT nodes are analysed in order to eventually start the activation of the other tasks.

Both the STAND−ALONE and SERVER node can be equipped with supplementary functionalities to monitor the environmental status (e.g. temperature, humidity, gas, etc.). In addition, all types of nodes can be equipped with an e-ink display [4] with the purpose from one side (CLIENT node) to replace the caption of an artwork and from the other side (ALL nodes) to provide information about the sensor status. Hence, a key feature of the proposed approach is certainly to be able to configure a smart cricket also in hybrid mode, for example, in such a way that it can be at the same time both the STAND-ALONE and CLIENT node (see Figure 3.3).

Figure 3.4 illustrates the network hierarchy with each type of node, with the related connections and features previously described.

3.2.3 The system architecture of a Smart Cricket

In this section the system architecture representing the core of each BeagleBone Black node of the *SMuNe* network in presented. The architecture consists of the following components:

- The **MACHINE** component represents the physical layer of the BBB node. The installed OS is a Debian Linux distribution, customized to ensure excellent performance and useful applications; at the same time such OS is able to provide

[4]http://www.pervasivedisplays.com

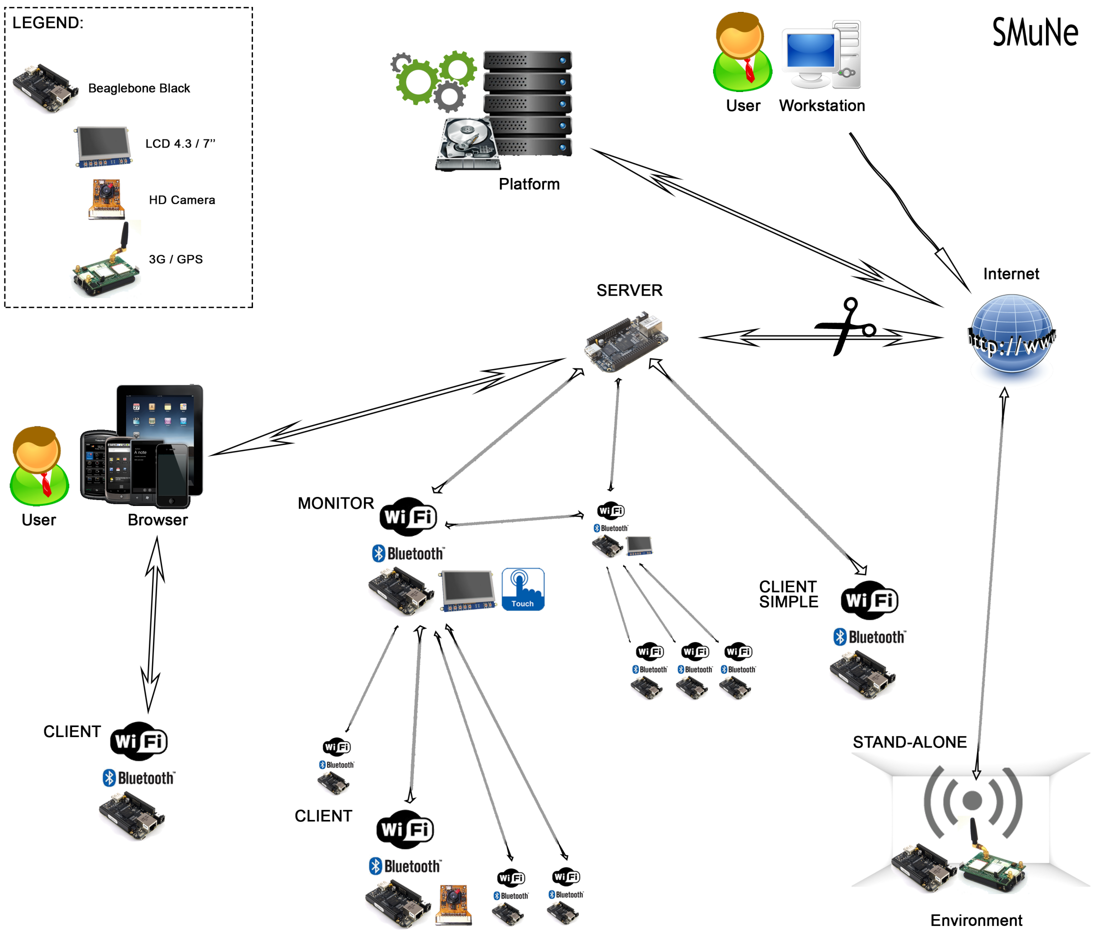

FIGURE 3.4: A hierarchical sensor network with types of BBB nodes.

the capability to extend the machine functionalities by recovering additional applications from several repositories. From a technical point of view, regarding the additional sensors and capes, a set of bash scripts and cron jobs accessing to different components and ensuring the proper resources management have been implemented. Finally, a web server configured and equipped with useful extensions is also installed.

- The **FRAMEWORK** component represents the software platform designed and deployed on the MACHINE component. This platform runs on a web server as it uses the *http* communication protocol. It is developed in *PHP* language by adopting the MVC pattern; moreover a number of extensions are enabled (curl, sqlite, mysql, imagemagick, gd, json, memcache, pdf, pdo).

- The **APPLICATION** component represents the implementation of the MVC architectural pattern.

- The **LIBRARIES** component consists of a set of libraries supporting the APPLICATION component; among these libraries should be noted: SLIM (a framework to create a RESTful system), REDBEAN (ORM for PHP), LOG4PHP (a library for managing LOG PHP), SMARTY (a template Engine for PHP), jQuery (a Javascript Function Library), Bootstrap (a front-End Framework).

- The **LANGUAGES** component have been designed to integrate the PHP and Python languages used to enable the communication between the platform and the hardware components.
- The **SENSOR LIBRARIES** component consists of a series of classes and Python libraries providing access to the additional hardware such as temperature, humidity, light intensity, pir, ultrasonic sensors.

3.2.4 The communication model

For what concert the communication between *SMuNe* nodes, the adopted model exploits the RPC (Remote Procedure Call) mechanism. In such model, the transmitter device that starts the communication activates a procedure on a remote device as if it was activated locally. In other words, the RPC mechanism allows a program to execute a "remote" subroutine on a "remote" computer (e.g. accessible through a network connection). Therefore, the concept of *transparency* cover a fundamental role in the RPC mechanism; indeed, the communication details on the network must be "hidden" to the end-user. To adopt such mechanism we rely on a PHP library named *JSONRPC* that implements the protocol JSON-RPC ver. 1.0 by encoding data in JSON format.
The communication model has been designed with the goal concept of simplicity, and the implementation is not far behind; in the follow the main task are described:
(i) a SERVER logs the classes needed to provide remote services and waits for requests,
(ii) a CLIENT creates an object of the remote class by RPC mechanism and calls the method of interest as if the class were local.
This communication model requires that any message has to be encoded in JSON format. In detail, each node realizes both the CLIENT and the SERVER role; in this way each device can effectively work as both applicant and services provider. This conception implements general purpose devices that can be specialized depending on the context, but at the same time can be re-configured easily and in a short time. In addition, each device implements a procedure to extract information about the provided services such as the procedure name, the input and output parameters, the description, etc. so that such information can be made available through a real-time service, as a source that each node can exploit to access and know neighbours functionalities. This modality allows the dynamically changing of the device settings by exploiting the connections provided by the node (USB or microSD card).

In order to enable a communication, the nodes that implement sensors whose information must be managed execute a series of cyclic calls (cronjobs) collecting such values. In particular, each cronjob starts the following sequence of actions (see Figure 3.5):

1. Collecting values from sensors,
2. Treatment of acquired values,
3. Saving values collected locally,
4. Starting a remote communication phase of such values,
5. Sending request with collected values
6. Holding response with outcome,
7. Analysis and storage of response message

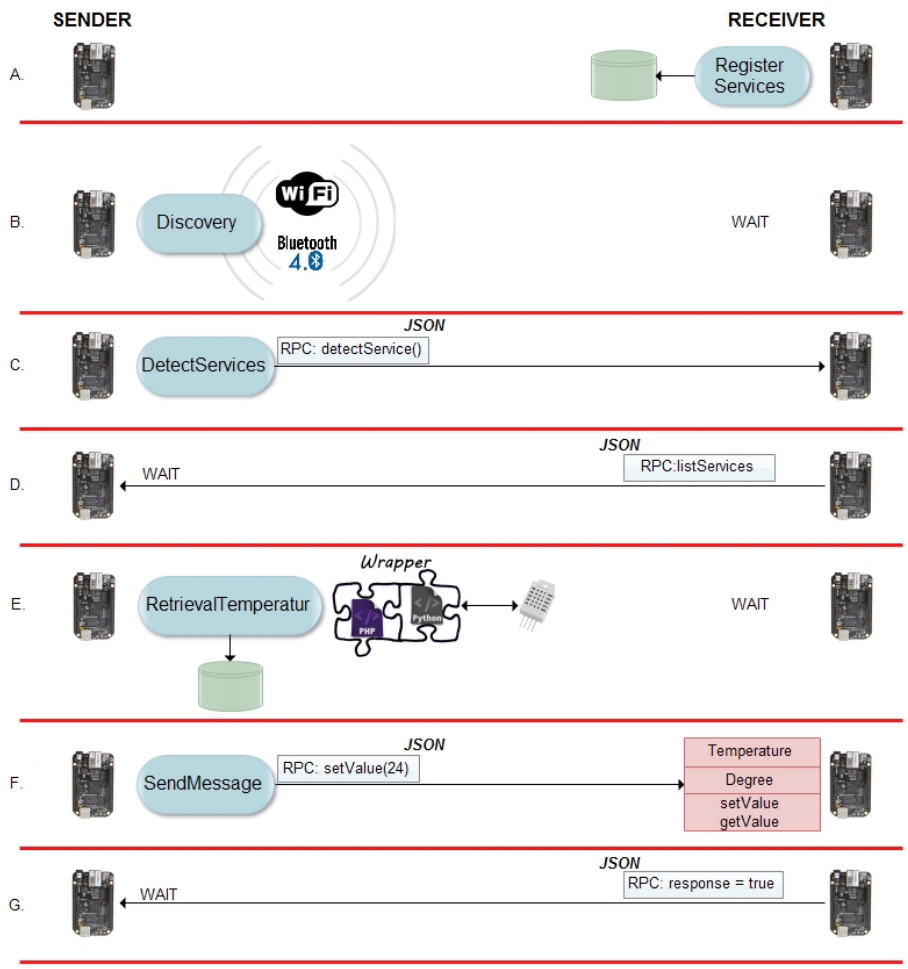

FIGURE 3.5: The communication model schema.

To successfully complete this sequence, the sender node has to know receiver one identity, in order to send the data; to address this issue, a scanning module to discover the presence of neighbours has been designed. The only prerequisite is the implementation of an interface such as Bluetooth and / or Wireless.

The scanning module performs a discovery phase analysing the presence of wireless/bluetooth nearby devices. When this phase is completed, each node analyses the list of discovered devices and processes it by filtering those that belong to the network category. The filtering is performed by means of SSID and DeviceName parameters with few changes that affect the different types, moreover the power value is used to verify the distance between two devices. Once such information have been processed, the communication phase can start. In detail, a node requiring such information will check this data list, retrieves the node of the required type in the first position (the closer) and sends a message; if the communication fails, the sender will keep track of the issue and tries to communicate with another available device on the list. This discovery phase starts every n minutes, where n is a value that can be manually set, but if necessary can be manually started. Through this modality, a node is able to communicate with any other type of device in its proximity, creating automatically adjacency maps in order to create dynamic routing mechanisms.

3.3 A Smart framework of intelligent services and communication technologies

The transformation of a static space into a dynamic and intelligent one can be performed through the adoption of the IoT paradigm and related ICT technologies; the infrastructure we propose aims to create and manage a smart cultural environment where knowledge will be transmitted in an intuitive and innovative way, exploiting multimedia and location-based services, user profiling and recommendation techniques, and mobile and context-awareness methodologies.

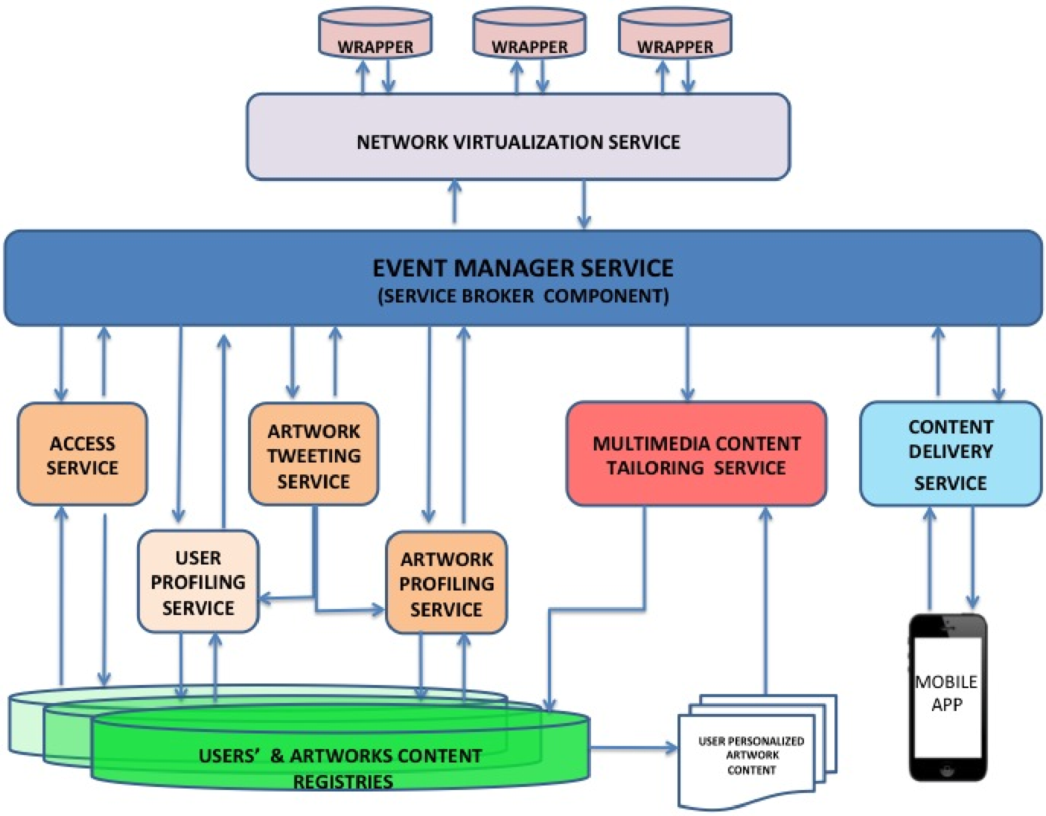

FIGURE 3.6: The smart service tier organization

This framework consists of a Service Oriented Architecture [87] with a set of services and components as shown in Figure 3.6. The pivot element is represented by the **Event Manager Service**, acting as a broker for the other services. All the implemented services are grouped and listed below:

1. Network Virtualization Service, Access Service, Artwork Tweeting Service
2. User Profiling Service, Artwork Profiling Service
3. Multimedia Content Tailoring Service

4. Content Delivery Service

3.3.1 The Event Manager service

Each time a change in the state of the Bluetooth and Wi-Fi Network systems is detected, an appropriate event is generated and suitably processed. The Event Manager Service relies on a software component, the Broker Component, acting as an asynchronous communication broker providing a notification mechanism based on the event publish/-subscribe paradigm. In particular, this component adopts the *Topic-based* subscription model, where notifications are grouped in topics and each subscriber will receive the notifications related to specific topics. By subscribing to a topic, a client service automatically receives notifications of all the events generated for that topic, thus becoming an event consumer. Notifications are delivered from the producer to the consumer through the broker, which allows a communication between publishers and subscribers, at the same time keeping them decoupled. The Broker Component exposes functions to register, subscribe and notify events as reported in Table 3.1.
The semantics associated with each topic reflects the functionalities yielded by the service which publishes it, and will be addressed in the respective section. Moreover, an ad-hoc Notification flow (see Figure 3.7) of the events related to these topics has been designed and implemented.

3.3.2 The Network Virtualization service

The *Network Virtualization Service* (NVS) handles low level information coming from the Wi-Fi and Bluetooth nodes acting in the exhibition area. It manages a set of networks and devices wrappers to detect preliminary the presence of new visitors' devices in the exhibition area; it also detects the proximity of authenticated devices to single or artworks group. When visitors access to the exhibition area and run the mobile App, the NVS (i) detects the presence of new devices in the Wi-Fi Network system, (ii) acquires the MAC Address of such devices along with the login information filled by the user in a App dedicated form, and (iii) publishes a new event `NEW_DEVICE` to start the artwork tweeting process in order to enable the multimedia content delivery. The NVS manages a pool of specific wrappers to ensure the correct communication stream enabling and supporting the correct content delivery process. The NVS relies on a software component, the *NetworkListner* module, to listen new connection requests coming from the network of the exhibition area and from the sensor node placed on the artworks' basements. When a new device logging request is detected, the NetworkListener module starts the handshake phase with the detected device and acquires the MAC Address of

TABLE 3.1: Listing of services

Topic	**Publisher Service**	**Subscriber Service**
NEW_DEVICE	Network Virtualization Service	Access Service
NEW_CONNECTION	Access Service	Artwork Tweeting Service
ARTWORK_PROXIMITY	Network Virtualization Service	Artwork Tweeting Service
DETECTED_VISITOR	Artwork Tweeting Service	User Profiling Service
OBSERVED_ARTWORK	Artwork Tweeting Service	Artwork Profiling Service
PROFILED_VISITOR	User Profiling Service	Multimedia Content, Tailoring Service
TAILORED_CONTENT	Multimedia Content, Tailoring Service	Content Delivery Service
NEW_DELIVERING	Content Delivery Service	Network Virtualization Service
SUCCESSFUL_DELIVERY	Network Virtualization Service	Content Delivery Service, Access Service
NETWORK_EXCEPTION	Network Virtualization Service	Access Service, Content Delivery Service
CONTENT_EXCEPTION	User Profiling Service, Artwork Profiling Service	Multimedia Content, Tailoring Service

such device along with the users' logging information (username and password). After acquiring the MAC Address and the identification information from the visitor's device, an event is generated.

```
NEW_DEVICE(NewDeviceMacAddress,USERNAME, PASSWORD, EventType)
```

is generated.

Information transmitted as parameters of the published event represent, respectively, the acquired MAC Address of connected visitor's device, Username and Password filled in by the user and the Event Type. For instance, if a new device with the `NewDeviceMacAddress = "A00823FR03MC"` is detected as incoming in the exhibition area and a visitor logs with Username = 'goofy' and Password = 'gopher', the NVS generates the event:

`NEW_DEVICE("A00823FR03MC", goofy, gopher, INCOMING)`

while the event:

`NEW_DEVICE(NULL, NULL, NULL, INCOMING_ANONYMOUS_NOTIFICATION)`

will be generated when a new device presence is detected in the exhibition area but no logging information were filled in. So, no connection requests were activated. This type of events will be discarded by the Access Service.

The NVS exhibits a reactive and context-dependent behaviour; automatic actions can be triggered in response to visitors' movements next to cultural objects. This behaviour can be described by means of a set of rules conforming to the **Event-Condition-Action (ECA)** architectural pattern. A typical **ECA** rule has the form:

`when<event>if<conditions>then<action>`

where <conditions> specifies the circumstances that must be verified for the <action> to be carried out whenever <event> occurs.

In this context <conditions> can be any logical combination of visitors staying in the surrounding area of an artwork while <action> may be the notification of the application of a specific alert or exception. Each semantic location in the artwork facility has its own A set of ECA rules are defined to establish if visitors next to an artwork is authenticated or not. For instance, if a visitor walks inside the surrounding area of the artwork identified by the `ID_Transmitting_Sensor` information, and he results coupled to a successfully authenticated device, a new event `ARTWORK_PROXIMITY` is published.

with the following parameters:

`ARTWORK_PROXIMITY(ID_Transmitting_Sensor, AuthDevMacAddress,EventType)`

For instance, if the authenticated user's device with the `AuthDevMacAddress = "A00823FR03MC"` is detected as incoming in the surrounding area covered by the Bluetooth sensor with `ID_Transmitting_`
`Sensor = "BTS05"`, the event published by the NVS looks like:

`ARTWORK_PROXIMITY("BTS05", "A00823FR 03MC", NEXT_TO)`

Otherwise, the component raises an exception. This behaviour can be formalized by the following ECA rule associated with each Artwork:

```
WHEN (NEW_DEVICE('A00823FR03MC',NULL,
NULL,'NEXT_TO'))
IF ( ∃ device ∈ Get_AuthenticatedDevice
('A00823FR03MC'))
THEN
<publish  ARTWORK_PROXIMITY('TS05',
'A00823FR 03MC', NEXT_TO)>
ELSE
<no action>
```

Table 3.2 lists the possible values assigned to the *EventType* field and recognizable by the NVS.

3.3.3 The Access service

The Access Service (AS) subscribes events published by the NVS and is engaged with the authentication process of logging users. When the NVS publishes a new `NEW_DEVICE` topic notifying the INCOMING Event Type, the AS extracts the Username and Password parameters and performs a query execution aimed at verify if the logging user is registered in the system. If the authentication process ends successfully, the AS, by invoking the *Network Translation Component* (NTC) software module, couples the MAC Address incoming from the NVS event with an IP address. Furthermore, the AS, by invoking a *Connection Manager Component* (CMC), creates a virtual connection assigning to it a unique identifier. Such connection identifier will be propagated in the succeeding events' notification to hold trace of the user's device activities. If the logged user is not recognized by the authentication system, an exception event is published and neither the NTC nor the CMC components are invoked.

The whole set of information are stored in an appropriate Connection Registry, holding the matching entry putting in relationship users (by his username), users' device (by the MAC Address of their mobile devices) and the assigned IP address on the exhibition Wi-Fi network. When the authentication process ends successfully, the AS publishes a `NEW_CONNECTION(`
`ID_Connection,IP _Device_Address,`
`Username)` event, subscribed by the Artwork Tweeting Service. Information used as parameters are represented by an `ID_Connection`, the assigned IP address, and the

TABLE 3.2: Listing of Events Type with description

Event Type	**Description**
INCOMING	A new device is coming in the artwork surrounding area. The connection is established and the MAC Address was acquired successfully
OUTCOMING	A connected device is going out from the artwork surrounding area. The connection will be closed and the assigned IP released
INCOMING_ANONYMOUS_NOTIFICATION	A new device presence is detected but the connection was refused (users with Bluetooth sensor enabled but no provided with the smart App) or problems occurred during the handshake phase. No MAC Address was acquired and the device is tagged as anonymous and it is inserted in a connection log file
OUTCOMING_ANONYMOUS_NOTIFICATION	An anonymous device is leaving the artwork surrounding area of the artwork
NEXT_TO	An authenticated device is coming in the artwork surrounding area
GENERIC_EXCEPTION	A generic exception has occurred

Username. The AS also shows a reactive behaviour dictated by a set of ECA rules. In this case, <action> consists in a series of operations aimed at formatting and generating a suitable query to the registered users' databases in order to retrieve the authentication data of a single visitor and show them in the proper place with the proper format. The AS does not directly execute the query, but it relies on the Data Service module to access the requested data, thus being independent of the particular legacy information DBMS.

For instance, the following ECA rule formalizes the visitors' authentication process: `NEW_DEVICE(A00823FR03MC, goofy, gopher, INCOMING)`

```
WHEN (NEW_DEVICE('A00823FR03MC', 'goofy', 'gopher', INCOMING))
IF (∃ username ∈ Get_Users('goofy')) THEN
<query the Users Registry for
visitors_password data>
<get the password>
<compare retrieved_password
with "gopher">
<authenticates or not the user>
<display successful
authentication message
on the wall monitor of user's device>
<assign a new connection identifier>
<publish NEW_CONNECTION event>
ELSE
<display an unsuccessful authentication message
on the wall monitor of user's device>
```

3.3.4 The Artwork Tweeting service

The Artwork Tweeting Service (ATS) subscribes events published by the AS and the NVS. It allows to distinguish the preliminary authentication process of the visitors from the time they will be next to an artwork. When visitors login in the system they only need to be authenticated and obtain a valid IP address. Until they aren't detected in the surrounding area of a cultural object, they don't receive any content or information. So, when the AS publishes a the `NEW_CONNECTION` event, the ATS holds information extracted by such event an waits to receive the `ARTWORK_PROXIMITY` event notification published by the NVS to start the Content Tailoring Process that enables the tweeting artwork metaphor, by publishing, respectively for the User Profiling Service and the Artwork Profiling Service, two events: `DETECTED_VISITOR(ID_Conn,ID_User)` and `OBSERVED_ARTWORK (ID_Conn,ID_Artwork)`.

3.3.5 The User Profiling service

Usually, the purpose of the visitor is to see and learn more and not to explicitly use the technology. Concisely, as stated in [138], the type of visitor's behaviour can be described through four metaphors and therefore classified as belonging to four different

stereotypes: the *ant* visitors (A), who follow a specific path and spend a lot of time observing almost all the cultural items, the *fish* visitors (B), who move most of the times in the centre of the room without looking at items details, the *butterfly* visitors (C), who do not follow a specific path, they are guided by the physical orientation of the objects and stop frequently examining their details, and finally, the *grasshopper* visitors (D), whose visit contains specific pre-selected cultural items, and spend a lot of time observing them.
At the act of registration, a system back-end Profiling Module submits to each user a simple questionnaire aimed to draw and associate the user to the most suitable profile. In this perspective, the User Profiling Service is responsible of the user classification stage. The first phase of such classification is **explicit** type, since it is the user that fills in the questionnaire. The information retrieved from such questionnaire (age, sex, occupation, yearly visits in cultural sites, reason for visiting, interest) represent a set of data that identifies each user, and usually do not change (or rarely change). Once the user have completed the questionnaire, these information are transferred to the Profiling Module and processed by a classifier by means of Weka API [5], a software module that performs several standard Machine Learning techniques. After an experimental stage performed in our laboratories, the *Decision Tree* as classifier type was selected for the explicit phase of user profiling. The following considerations motivate our choice:

- with respect to a *Bayesian Network* classifier, the *Decision Tree* has an easily observable behaviour as it is possible to have an "explanation" of the decision. In addition, it may contain different sets of variables that are not connected in any way.
- a *Neural Network* classifier is computational expensive than the others classifiers mentioned; this is not a positive feature for a real-time system.
- the main advantages offered by a *Decision Tree* classifier are the simplicity and speed during the training and operational phases.

For a proper use of a classifier during the explicit user profiling phase, it needs a training set of data to complete a training phase. According to this requirement, a training data set was built up, by subjecting to 150 volunteers the questionnaire before starting the infrastructure deployment. These volunteers have been enrolled from heterogeneous classes of membership, in particular from universities, research centres, social networks (e.g. Facebook), and schools.

In order to improve and refine the profile of a visitor in a dynamic way, there is the need to take into account another phase of users' classification: the **implicit** type one.

[5] http://www.cs.waikato.ac.nz/ml/index.html

It does not require a direct user intervention since the Profiling Module collects the visitors' behaviour and stores it in a structured LOG file. In the following, we report a short example of a visitor LOG file using our system.

```
<?xml version="1.0" encoding="UTF-8"?>
  <USER ID='UI001'>
          <STEREOTYPE_USER>2</STEREOTYPE_USER>
          <START_SESSION></START_SESSION>
          <END_SESSION></END_SESSION>
    <TRANSACTION>
     <REQUEST>
        <HTTP_METHOD>GET</HTTP_METHOD>
        <PATH_INFO>/opera</PATH_INFO>
        <REQUEST_PARAMETERS>
           <CODEARTWORK>ART0224VICTA</CODEARTWORK>
           <DATE>13/05/2013</DATE>
             </REQUEST_PARAMETERS>
           <REMOTE_ADDRESS>192.168.1.6</REMOTE_ADDRESS>
    </REQUEST>
      <PARAMETERS_LOG>
           <HOUR_LISTEN_START>13/05/2013 13:58:12</HOUR_LISTEN_START>
           <HOUR_LISTEN_END>13/05/2013 14:05:42</HOUR_LISTEN_END>
           <AUDIOS>
      <TOT_NUMBER>3</TOT_NUMBER>
      <AUDIO ID='AU1111'>
               <HOUR_END>13/05/2013 14:00:42</HOUR_END>
        <LENGTH>180</LENGTH>
    </AUDIO>
        </AUDIOS>
           <IMAGES>
      <TOT_NUMBER>11</TOT_NUMBER>
      <IMAGE ID='IM1122' />
      <IMAGE ID='IM1134' />
        </IMAGES>
           <VIDEOS>
      <TOT_NUMBER>2</TOT_NUMBER>
      <VIDEO ID='VI3333'>
               <HOUR_END>13/05/2013 14:20:12</HOUR_END>
        <LENGTH>180</LENGTH>
    </VIDEO>
        </VIDEOS>
           <TEXTS>
      <TOT_NUMBER>4</TOT_NUMBER>
      <TEXT ID='TX4455' />
             <TEXT ID='TX4456' />
</TEXTS>
     </PARAMETERS_LOG>
  </TRANSACTION>
```

```
</USER>
```

The LOG file stores the following visitor behaviour features: (i) the beginning and the end of the visit (ii) all the mobile App requests to the retrieval of multimedia content (e.g audio, video, text, image) (iii) the start time and the end of listening/watching a audio/video file. An ad-hoc algorithm parses the LOG, extracting some implicit information about the user, such as:

- User ID
- Average time observation of an artwork
- Percentage of observed artwork
- Visit duration
- Percentage of audio heard
- Percentage of videos viewed
- Average number of images displayed
- Average number of texts read

An artwork can be considered as *observed* if (i) the sensor detects the visitor presence in its surrounding area and (ii) the mobile App requests at least one multimedia content about the related cultural item. This implicit phase of user profiling takes strongly into account the interaction between the user and the available multimedia content, in order to associate him the stereotype that better join, from one side to its behaviour inside the environment, from the other side to its relationship between suggested multimedia objects.
The parsing of the behavioural LOG files can be executed:

- Off-Line: At the end of the user session, in particular, it can be carried out during the night. In this case the users will benefit their updated profiles during upcoming visits.
- On-Line: Periodically (every 15/30 minutes), the algorithm can compute the user behaviour parameters, and then update the database and consequently the user stereotype.

This additional information will be the input data for a classifier in order to derive and refine the users' stereotype. After an experimental phase, the classifier chosen is the *Bayesian network* type, because it is particularly effective even in the absence of some input parameters. These approaches regarding the stereotyping process and Machine Learning techniques, adapted and tailored for the cultural heritage enjoyment needs, are inspired and follows the criteria in [92, 93, 133, 137].

3.3.6 The Artwork Profiling service

The Artwork Profiling Service (APS) subscribes the topic `OBSERVED_ARTWORK (ID_Conn, ID_Artwork)` published by the *Artwork Tweeting Service* and publishes the topic `PROFILED_ARTWORK`. It starts a query process towards a multimedia content repository (artworks multimedia content DB) to retrieve the complete list of the available content. Such list is published as a parameter of the `PROFILED_ARTWORK (ID_Conn,ContentList)` event. When a visitor is next to an artwork, the Artwork Tweeting Service publishes the `ID_Artwork`; such event is handled and the APS prepares and submits a new query request to the Content Repository; the result set contains the artwork denomination field and the complete list of available content for that artwork. The retrieved content list is a link to an array-list containing the pointers to each content instance. Such pointers will be used by the *Multimedia Tailoring Content Service* component to access the content descriptions and select among the whole list only those ones are matching user profiling features. The multimedia recommendation techniques and the management of multimedia data, arranging the *Multimedia Tailoring Content Service*, will be discussed in the next section.

3.3.7 The Content Delivery service

When a new collection of personalized content is available from the MCT Service, a new delivery stream is organized. The Content Delivery (CD) Service is engaged with the optimization and organization of the content delivering streams. For instance, if the amount of content selected by the MCT service is large, a pre-caching operation would be implemented. When the stream is ready, by publishing the `NEW_DELIVERY` event, such new event is notified to the NVS that is directly engaged with the final part of the delivery process. The NVS selects the appropriate device wrapper to optimize the forwarding process and the rendering of content in users' devices. The NVS, by using the `ID_Conn` information, retrieve the IP address of the user's device and starts the stream of content delivery. If all the content are successfully delivered, a `SUCCESSFUL_DELIVERY` event is notified to all system components. If delivery process fails, an exception occurrence is notified by pushing the `NETWORK_EXCEPTION` event.

Accordingly, after the mobile device has received the adapted content, the results have to be presented to the user. From this moment, the user can use three levels of refinement: (i) pointing to a specific content among those ones presented in the delivered list; (ii) selecting facets of resources relevant to the current location and heading, where cultural related facets are location, event, artwork and people, and (iii) selecting sub-facets of the selected facet, e.g. painting, photograph, artist.

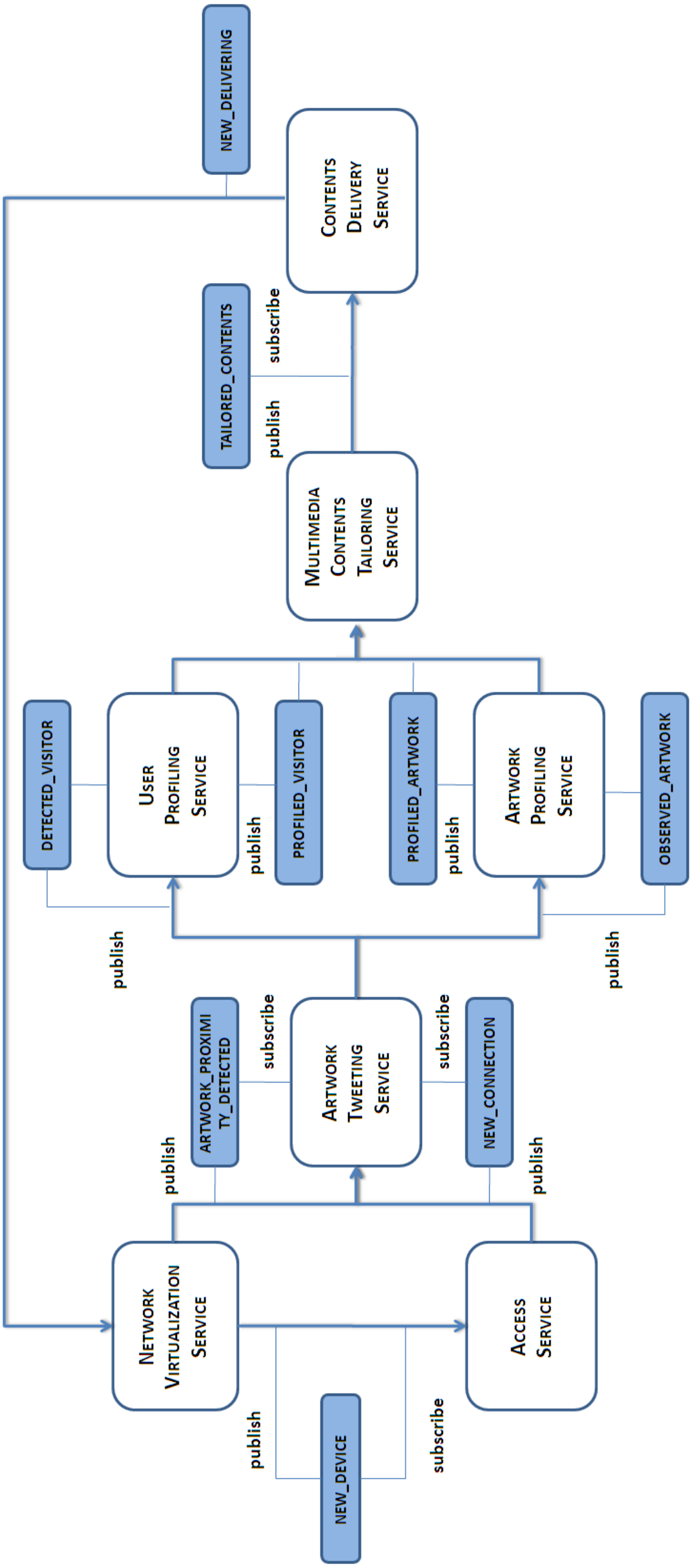

Figure 3.7: The Topics Notification flow: from a new mobile device detected to the content delivery.

3.4 Proximity detection: a discovery strategy enabling location-based services

Over the years, there has been a number of technologies proposed for proximity detection. Approaches such as those used by Meme Tags [94] provide good accuracy but require line of sight. Proximity detection is one of the advanced location based service (LBS) functions [95–97] to automatically detect when a pair of mobile targets approach each other closer than a predefined proximity distance (as in location alerts of Google latitude). There are some proximity detection works using Bluetooth signal. From a specific work perspective, the works of [98, 99] are highly relevant to the paper. In those studies, the authors use the ability to detect Bluetooth signals as indicators for people nearby within the Bluetooth range (around 10 meter). For what concert the use of mobile phones, the authors in [100] proposed a system for proximity detection using Bluetooth, suggesting a new form of path loss model which takes into account the relative orientation of mobile phones. Moreover, in [101] a proximity estimation model to determine the distance based on the RSSI values of Bluetooth and light sensor data in different environments is presented.
In this scenario, the discovering strategy of a cultural object and its associated Smart Cricket is a crucial aspect of this work and it is performed by means of a designed proximity algorithm that makes use of Bluetooth Low Energy (indoor scenario) or WiFi (outdoor scenario) communication technologies. The paradigm is of pull-type; the algorithm scans for active networks when the App discovery page is selected by the user, starting an artworks discovery phase. If a user begins to enjoy the multimedia content the discovering will be interrupted. The algorithm consists of two main phases and related details are described as follows:

1. BLE/WiFi Networks Discovery
2. Winning BLE/WiFi Network Declaration

Phase 1: BLE/WiFi Networks Discovery: this phase is performed by a software module composed by a set of daemon processes running on users' device that manage a scanning process to seek all BLE/WiFi networks (with a specific identifier) sensed from users' location. The output of this step is a list of active sensed BLE/WiFi networks.

Phase 2: Winning BLE/WiFi Network Declaration: this *gaming phase*, during which each discovered network races to be the winner (the closest to the user), represents the core of the proximity algorithm. It takes as input, from the first phase, the list of sensed BLE/WiFi networks identifiers, corresponding to the list of cultural items retrieved in the previous phase. Then, it starts a computing process of the RSSI [6] values measured in correspondence of each network, in order to assess the winning one (the network with the strongest power signal). Although the RSSI parameter is widely used in literature [102–104] to establish the position of an object inside a space, the majority of the approaches need for dedicated hardware infrastructure in order to calculate the estimated position; in detail, the RSSI values collected have to be sent to a server workstation and consequently processed. The algorithm novelty lies in the fact that it is able to estimate the proximity of a user to an object running exclusively on a smartphone without needing a computing infrastructure or additional techniques (e.g. clustering of the RSSI values).

Since we aim to catch the visitor perspective and behaviour (the artwork that could interest him) and not his punctual position inside the space, the adopted criteria establishes that the winning network is that one associated to the highest RSSI value. Such value is estimated computing a weighted average by means of three succeeding measures of each RSSI and such weights were computed by running a calibration algorithm. RSSI measurements are conditioned, as known from literature, by the environments in which they are performed. In this perspective, during laboratory experiments it was observed that more reliable and effective RSSI measurements were those sampled in succeeding time instants and differing each other of very low quantities. If for three succeeding times we register a very similar value then we can assess that such RSSI measure is reliable. Hence, the deputed winner network is that one showing the minimum distance value among its three succeeding RSSI samples; accordingly an observation window holds three succeeding RSSI samples for each network appearing in the input list. Only networks having the observation window filled up, can races in the gaming phase; other ones are discarded from this phase until they will collect again three succeeding samples. Summarizing, the algorithm owns a map of sensed networks. Each network is characterized by an identifier (both for BLE and WiFI), a symbolic network name (a name string), and an Observation Window structure containing the actual sampling instant RSSI value and the two previous time instants RSSI samples. The winning network is that one owns the highest RSSI value, estimated with a normalized weighted average computed on the three RSSI samples. As a software entity, each anchor network is so characterized as a triple containing:

[6] In telecommunications, received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal. It is a generic radio receiver technology metric, which is usually invisible to the user of the device containing the receiver, but is directly known to users of wireless networking of IEEE 802.11 protocol family.

Anchor_Network_Object=<SSID,
SymbolicName, RSSI_ObservationWindow>

The *RSSI_ObservationWindow* is implemented as a three elements vector, collecting three succeeding RSSI samples:

RSSI_ObservationWindow=[RSSI_Value(t_{k-2}),
RSSI_value(t_{k-1}),RSSI_value(t_k)]

where t_k is the sampling time. The "distance function" adopted to compute the minimum RSSI values distance for each anchor network follows:

RSSI_distance_values=abs {RSSI_value(t_{k-1})-abs [RSSI_value(t_k)] } / {
abs[RSSI_value(t_k)] / *max_dbm*}**K*

where *max_dbm* is the maximum *dbm* value between the scanned networks, and K is a normalization value suggested by the experimentations.

In Figure 3.8 we report an example of use of the algorithm. Inside the space are located four items equipped with a sensor node; each node emits a Bluetooth Low Energy signal whose power (RSSI) is captured by the algorithm that computes the winning network representing the sensor node, associated to a cultural items, closest to the visitor within the space (in the example, **item_1** network is the winner).

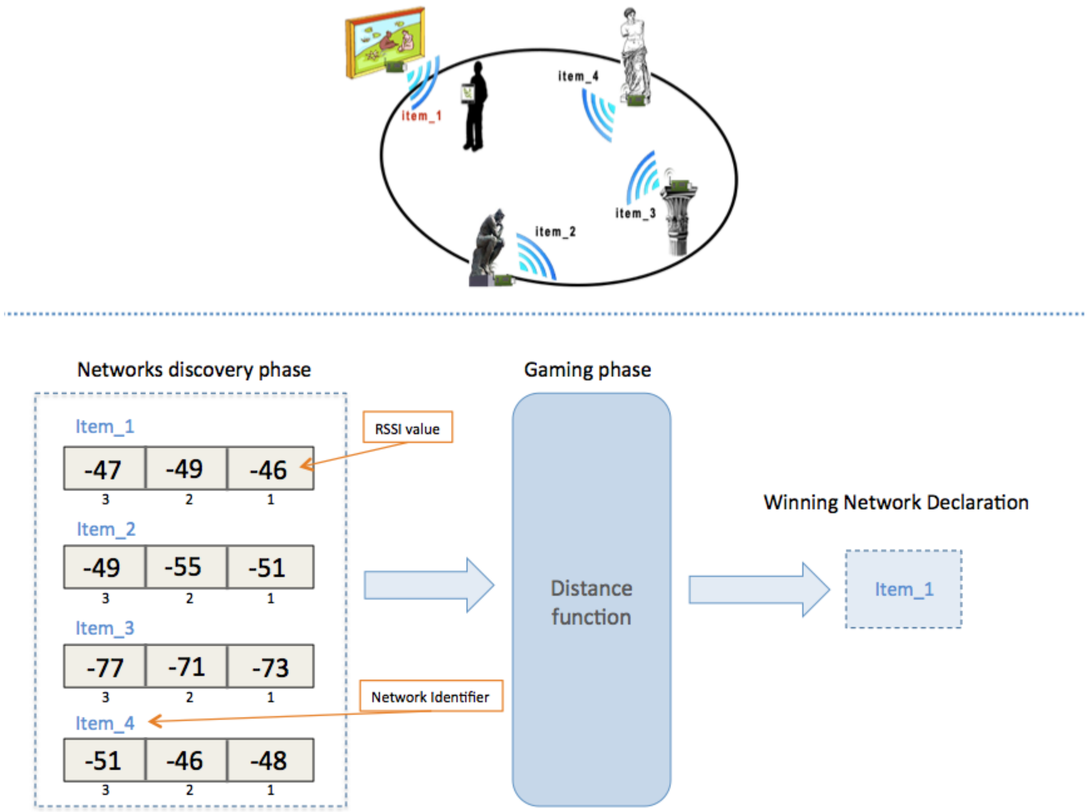

FIGURE 3.8: Proximity algorithm: an example of use.

3.5 The context-awareness

Modelling the context through the evolution of its instances is a complex operation, requiring a modular architecture to support this activity and to manage the general conditions. In this section the Context Evolution System architecture and its components are presented and detailed. Figure 3.9 illustrates a functional overview of the proposed system, composed of the following main components:

- **Services Engine**: this component represents the core of the CES system; it is an engine responsible for events management and the context switching. Moreover, it is composed of three sub-modules:

  Events Detector: this module is responsible for (i) capturing events (e.g. a sensor detecting too high a temperature within a room, a sensor detecting a visitor in proximity of a cultural item, a sensor detecting an emergency situation, etc.) and (ii) activating the Context Switching Computation module.

  Context Switching Computation: this module, triggered by the Events Detector, is responsible for the context-switch and the dynamic selection of *Contextual Data Views* (useful data to be presented) and the *Basket of Services* (useful services to be offered).

  Visiting Paths Generation: this module is responsible for arranging items in appropriate visiting paths provided to visitors (e.g. cultural objects arranged in a cultural path within an exhibition).

- **Services Deliverer**: this component is responsible for the services adaptation and delivery to users. For instance, consider the situation in which a user is located in proximity of a cultural item: (i) as a first step, its presence will be detected by a deployed sensor (*an event*), (ii) the context changes and the Services Deliverer enables the multimedia guide service in order to provide multimedia information to the user through its mobile device.

- **Knowledge base and User LOG**: these components can be considered as repositories that manage respectively (i) multimedia data, in order to propose objects and content of interest to users arranged in the shape of visiting paths, and (ii) captured users behavioural logs.

- **Context Manager**: this component is responsible for managing the current context by constantly storing the overall information (data) characterizing the context at a given moment (e.g. environmental data, user data, time information, etc.).

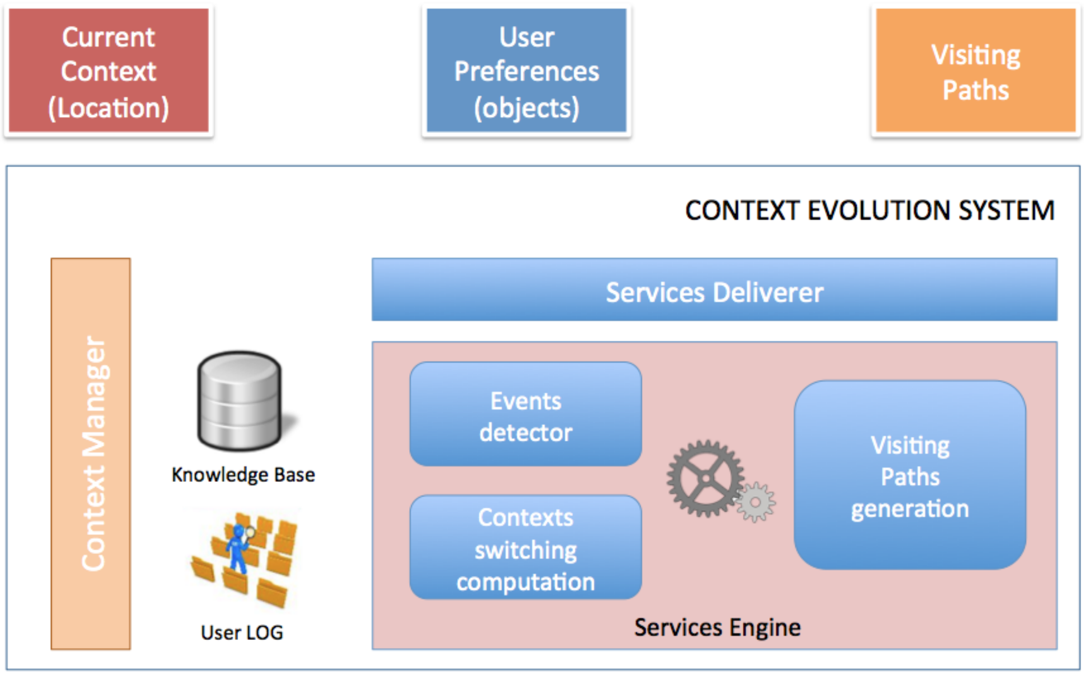

FIGURE 3.9: The Content Evolution System

The rationale behind this system's design derives from two main requirements: (i) to simplify the access to and enjoyment of cultural items and spaces, (ii) to adapt this system to the different environmental characteristics and needs. The modularity of the proposed approach guarantees the applicability of the system in different scenarios, such as the smart transport domain. Indeed, the Visiting Path Generation module can be replaced by one or more different modules in order to manage different situations.

3.6 Multimedia Recommendation and Data management

In this section we discuss and detail the adopted techniques to recommend and tail multimedia data in order to improve the user experience during a cultural visit. In our infrastructure, such techniques are managed by the Multimedia Content Tailoring Service. The MTC Service is engaged to discover the correct matching between users' profile and cultural items' multimedia content.
Extracting the information supplied by the UPS and the APS, the MCT service exploits the User Profile ID field to access the ContentList Table and looks for correspondences. The majority of approaches of content tailoring in the multimedia realm generally exploits high level meta-data, often extracted in automatic or semi-automatic way from low level features. However, these approaches suffer from several drawbacks:

- (i) it is not always possible to extract in automatic and effective way useful high level information from multimedia features,
- (ii) for some kinds of multimedia data there is not a precise correlation between high and low level information,
- (iii) there is not always available explicit and useful information about user preferences and feedbacks.

The adopted approach tries to avoid such drawbacks: (i) analysing in a separate way low and high level information of an object, (ii) exploiting the LOG files to implicitly determine information about an user, (iii) considering as relevant content for the selection the features of the object that a user is currently observing together. Therefore, we try to merge in a unique strategy some aspects of multimedia information retrieval with the basic theory of modern adaptation systems. The idea behind this approach [124, 125] considers that when a user is located in the surrounding area of a cultural object, the system is able to: (i) capture this event; (ii) extract the set of available multimedia objects related to the object; (iii) filter only the set of candidate multimedia matching user preferences [133]; (pre-filtering strategy); (iv) arranges such objects in apposite fruition paths considering the stereotype of the user describing the user behaviour (visit duration time and movements inside the space) by means of four metaphors (post-filtering strategy).

3.6.1 Management of Multimedia Data

The data and retrieval models we propose are inspired by the Windsurf ones [123, 127] as follows.

3.6.1.1 Data model

We consider a database $\mathcal{O}$ of M multimedia resources,
$mathcalO = \{O_1, ..O_M\}$, such as images, videos, and texts, where each resource O is characterized of m_o elements, $O = \{o_1, ..o_{mo}\}$ representing, regions of an image, shots of a video, and parts of a document, respectively. Each element o is described by way of low level features F^l that represent, in an appropriate way, the content of o (e.g., the colour distribution of image's regions). Although we consider for an image/keyframe its regions and for each region its visual features, representing an image/keyframe as a set of local features, like SIFT [119] and SURF [120], is also easily achievable within the Windsurf framework. In particular, images are segmented into regions, where pixels included in a single region share the same visual content (i.e., color/texture) [127]. Videos are first segmented into shots [130]. Then, each shot is represented by a single representative keyframe (e.g., the first frame of the shot). Each keyframe is first segmented into visually coherent regions, then color/texture features are extracted for each keyframe region [127]. Documents are modelled as a set of pages. In order to enrich data representation, objects are also annotated by the *Features Extractor* module with high level (semantic) descriptors F^h (e.g., annotations concerning the history of a paint, experts' descriptions of an an- cient manuscript, visitors' descriptions and reviews, keywords describing what a video shot (or an image) is related to, etc.). We define the universe of semantic descriptors $\mathcal{F}$ as the union of all annotations (both meta-data and (semi-)automatically provided labels) associated to objects in $\mathcal{O}$. The association between an object o and its descriptors is modelled by way of a membership relation $R \subseteq \mathcal{O}x\mathcal{F}$ that indicates that object O has assigned an annotation in $\mathcal{F}$.

3.6.1.2 Retrieval model

As for the retrieval model, given a query object $Q = \{Q_1, ..Q_m\}$ composed of m elements, and an element distance function δ, measuring the dissimilarity of a given pair of elements (using their features), we want to determine the top - k objects in O that are the most similar with respect to Q. Similarity between objects is numerically assessed

by way of a object distance function d_{F^l} that combines together the single element distances into an overall value. Consequently, resource O_a is considered better than O_b for the query Q_i if $d(Q, O_a) < d_{F^l}(Q; O_b)$ holds [128].
The computation of the object distance d_F is obtained by combining three basic ingredients: (i) the element distance δ, (ii) the set of constraints that specify how the component elements of the query Q have to be matched to the component elements of another (database) object O, and (iii) the aggregation function that combines distance values between matched elements into an overall object distance value (e.g., a simple average of distance values between matched elements). The efficient resolution of queries over features is ensured by a employing indices built on top of elements (e.g., image regions, and video shots) based on the M-tree metric index [129]. In order to enrich data representation, objects are annotated with high level (semantic) descriptors S (e.g., labels describing what a video shot is related to). Such descriptors are in the form of keywords (or tags) and are semi-automatically assigned to objects by means of a multimedia annotator that, starting from a training set of pre-annotated objects, is able to predict sets of "good" tags able to effectively characterize the content of new untagged objects [131].
The universe of tags T is defined as the union of all possible semantic descriptors to be associated to objects in O, and the membership relation $R \subseteq OxT$ that indicates that an object O has assigned a tag in T. The annotation process is modelled as a nearest neighbours (NN) problem on object elements and turn into a set of graph-based problems. First, we try to discover affinities between tags and an unlabelled object, which is done using a Random Walk with Restart algorithm on a graph that models current annotations as well as elements' similarities. Then, we compute pairwise tag correlations. Again, this relies on the analysis of links in a (second-order) graph. Finally, we combine the results of the two steps to derive a set of terms which are both semantically correlated each other and affine to the new object. This final step amounts to solve an instance of the Maximum Weight Clique Problem on a small graph. Note that, while for objects of type image tags are directly associated to images, when annotating videos, we are able to predict tags not only for shots but even for videos, by opportunely propagate tags at the shot level to the video level [130]. Given a user-provided set of tags, as query semantic concepts, objects are selected by the query processor by applying a co-occurrence-based distance function d_S on T. The search provides the set of objects (i.e., images, videos/shots, documents) that share at least one tag with the input set. Both low level features and semantic descriptors concur to determine the multimedia relatedness $d(O^i, O^j)$ among two objects. In details, if O^i and O^j are of the same type (e.g., we are comparing two images), we define their global distance as the average between the contribution given by low level features and the one provided by semantics, that is: $d(O^i, O^j) = d_{F^l}(O^i, O^j) + d_S(O^i, O^j)/2$; on the other hand, if we are comparing

objects of different type (e.g., a document with a video), their *multimedia relatedness* equals to their semantic distance only, $d(O^i, O^j) = d_S(O^i, O^j)$.

3.6.2 Recommending multimedia data

When a user is near to a cultural item, the system has to be able to:

- (i) determine a set of candidate objects for the telling process on the base of user needs and preferences (*pre-filtering phase*);
- (ii) opportunely rank these objects exploiting their intrinsic features and users' past behaviors (*ranking stage*);
- (iii) dynamically arranges the selected objects in apposite "fruition paths" considering other context information such as environmental conditions (*post-filtering phase*).

3.6.2.1 Pre-filtering phase

Each object subject to recommendation may be represented in different and heterogeneous feature spaces. For instance, the picture of a artwork may be described by annotations concerning its history, the materials it has been built with, low-level image features, experts' descriptions, visitors' descriptions and reviews, and so on. Each of these sets of features contributes to the characterization of the objects to different extents. Hence, it is important to consider congruently each type of descriptor during the recommendation process. The first step consists in clustering together "similar" objects, where the similarity should consider all (or subsets of) the different spaces of features. To this purpose, we employ high-order star-structured co-clustering techniques [133] to address the problem of heterogeneous data pre-filtering. In this context, the same set of objects is represented in different feature spaces. Such data represent objects of a certain type, connected to other types of data, the features, so that the overall data schema forms a star structure of inter-relationships. This task consists in clustering simultaneously the set of objects and the set of values in the different feature spaces. In this way we obtain a partition of the objects influenced by each of the feature spaces and at the same time a partition of each feature space. The pre-filtering phase leverages the clustering results to select a set of candidate objects by using the user's profile, which is modelled as sets of descriptors in the same spaces as the objects' descriptors.
Let $\mathcal{O} = \{O^1, ..O^M\}$ be a set of M multimedia objects and $\mathcal{F} = \{F^1, ..F^N\}$ a set of

N feature spaces. A dataset can be viewed under the different views given by the different feature spaces F_k. Therefore, the view k is associated with each feature space F_k. Given a star-structured dataset $\mathcal{SD}$ over $\mathcal{O}$ and $\mathcal{F}$, the goal of the star-structured data co−clustering is to find a set of partitions $\mathcal{Y} = \left\{Y^1, ..Y^N\right\}$ over the feature set $\mathcal{F} = \left\{F^1, ..F^N\right\}$ and a partition X of the object set $\mathcal{O}$ by optimizing a certain objective function. To solve the high−order star−structured co−clustering problem, several algorithms have been proposed based on different approaches. In this work, we adopt a parameter−less iterative algorithm that maximizes the Goodman-Kruskal τ , a statistical measure of association that automatically identifies a congruent number of high-quality co−clusters [132]. In our recommendation problem, a user is represented as a set of vectors $U = \left\{U^1, ..U^N\right\}$ in the same N feature spaces describing the objects. Each vector u^k is updated each time the user visits (or re−visit) an object by considering the object features in each space at the instant of the visit. To provide a first candidate list of objects to be delivered, we measure the cosine distance of each user vectors associated to the k−th space, with the centroids of each object clusters in the k−th space. For each space, the most similar object cluster is chosen leading to N clusters $\{X_1^c, ..., X_N^c\}$ of candidate objects. Then, two different strategies can be adopted to provide the pre-filtered list of candidate objects O^c : (i) set-union strategy − the objects belonging to the union of all clusters are retained, i.e., $O^c = \bigcup_k X_k^c$, (ii) threshold strategy − the objects that appears in at least the clusters ($this \in \{1, ..N\}$)are retained.
The first strategy is suitable when user's vectors are associated to very small clusters (e.g., because the user likes very uncommon objects). In any other situation, the second strategy is the most appropriate. As a final step, objects already visited/liked/browsed by the user are filtered out. Notice that, thanks to this approach, users are not described by set of objects, but by sets of features that characterize the objects they visit, like or browse.

3.6.2.2 Ranking and Post-filtering phases

Finally, the list of suggested items, which are selected as interesting by users, is organized in apposite fruition paths (considering the user stereotype). The recommendation grades of multimedia objects, which come from certain cultural items with a certain number of visitors or with particular negative values of rating, are penalized and such objects could be excluded from recommendation. In particular, we use a novel technique that has proposed in previous works [121, 122], combining low and high level features of multimedia objects, possible past behavior of individual users and overall behavior of the whole "community".

Chapter 4

Assessment and Validation

4.1 *The Beauty or the Truth* case study

As an assessment scenario, a wide case study is discussed; it consists of an art exhibition of over than 271 sculptures divided into 7 thematic sections and named *the Beauty or the Truth* [1]. This exhibition shows, for the first time in Italy, the Neapolitan sculptures of the late nineteenth century and early twentieth century, through the major sculptors of the time (see Figure 4.1). The sculptures are exhibited in the monumental complex of San Domenico Maggiore, located in the historic centre of Naples, Italy.

FIGURE 4.1: The Beauty or the Truth exhibition.

The environment provides a Wi-Fi connection with a mobile-based access to a multimedia collection containing: digital reproductions of sculptures by Francesco Jerace and other artists, educational videos, audio guides and textual and hypermedia documents with descriptions of authors and sculptures. The user's visit starts with preliminary

[1] http://www.ilbellooilvero.it

booking and ticketing phases; after these steps have been completed, the visitor can walk within the exhibition rooms .When he/she is particularly close to a sculpture, its mobile device, equipped with a mobile application named *OPS Opere Parlanti Show* (The Talking Artwork Show), is detected by the sensor node placed on the cultural item. Once the user's mobile device has been detected, the system captures this event, performs a context switch arranging useful multimedia data and activating the most appropriate available services. The multimedia content (texts, audio, video and images) of the exhibited cultural items are stored in the knowledge database of DATABENC [2], the high technology district for the Cultural Heritage in Campania (Italy). The *The Beauty or the Truth* exhibition can be considered as smart, since it is characterized by a wide but non-invasive presence of technological instruments with the aim to animate the static exposed sculptures. The *talking artwork* metaphor we enabled during the exhibition relies on the Internet of Things (IoT) paradigm (see Figure 4.2) by using smart nodes, proximity detection methodologies and a mobile application as end-point of the enjoyment process. A smart node, deployed near an artwork or a group of artworks, is able to create a surrounding area through Bluetooth Low Energy capabilities; if a visitor approaches the surrounding area, the artwork begin to propose itself telling a story through multimedia facilities.

4.1.1 Implementation details

The system was deployed and tested inside the *the Beauty or the Truth* exhibition; in Figure 4.4 the environment layout is illustrated. Each exhibited sculpture or each subset of sculptures, was equipped with a sensor node with Bluetooth Low Energy (named the SLAVE node), while in each room one or more sensor node was deployed (named the SERVER node) with environmental monitoring capabilities (temperature, humidity, CO, smoke and air quality). In particular, the SERVER nodes creates a Wi-Fi area inside the exhibition and is also responsible for the multimedia content delivery. Overall, more than 70 SLAVE nodes and 10 SERVER nodes were installed. To enable the multimedia service delivery, a mobile application, named *OPS Opere Parlanti Show* (the Talking Artwork Show) was designed and is currently available on the main smarphone app stores. Visitors can download and install it on their mobile device in order to start a novel cultural experience. The multimedia collection is composed of about 1500 images, 500 audio files (Italian and English languages), 300 video files and over 1000 text files, all relating to the exhibited sculptures. The graphic elements placed in the rooms are represented by captions (one for each sculpture), indicating the name, the author, the

[2]http://www.databenc.it

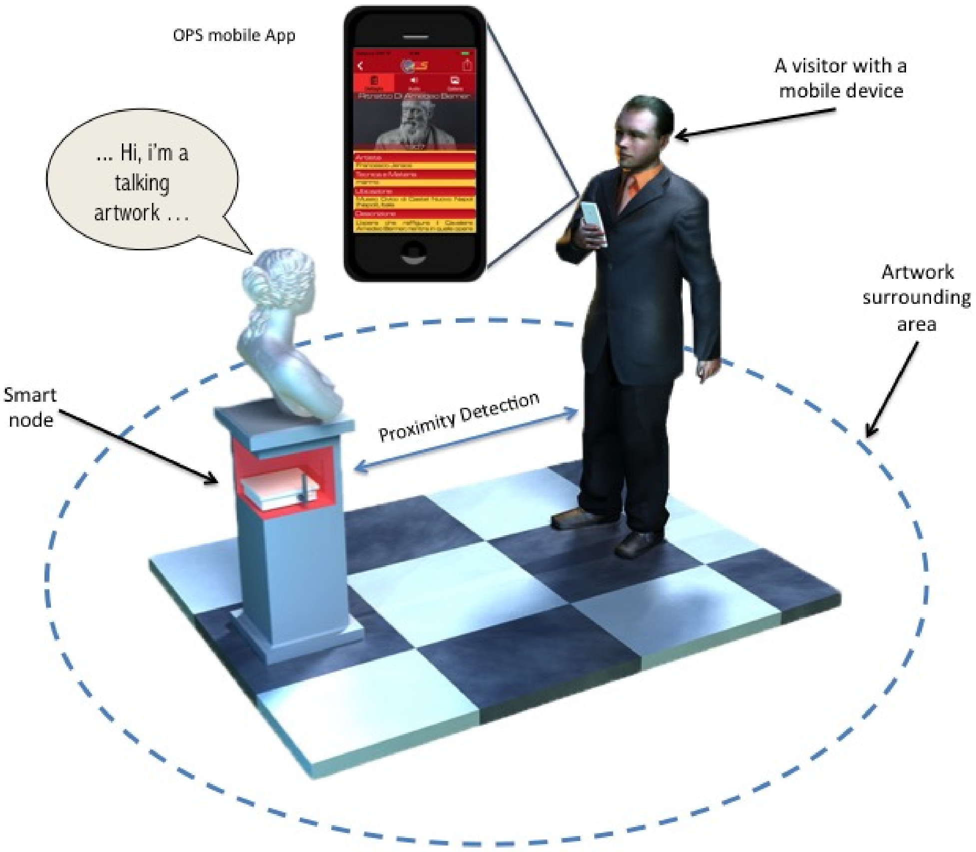

FIGURE 4.2: The talking artworks metaphor.

historical period and the material, and information panels in each section. The exhibition (see some related photos in Figure 4.3) has recorded about 45,000 visitors since the date of opening (30 October 2014).
Moreover, the system has been implemented by ad-hoc JAVA libraries, within the Groovy-based GRAILS web framework and exploiting multi-threading facilities. Communication logs have been stored into a proper repository managed by the Nosql DBMS Cassandra. The system exploits additional ad-hoc software libraries realized in [64] to build multimedia stories related to the cultural objects and to recommend customized visiting paths. The client requests are elaborated by JAVA Servlets and the results are sent to the client in Json format.

4.1.2 A Mobile Application as end-point of the fruition process

From the point of view of enjoyment and fruition processes that our system aims to provide to the end-users (e.g. visitors, tourists, citizens and so on), designing a mobile application is absolutely one of the main tasks. The App and the mobile device became the instruments through which the knowledge can be transmitted to the people in the form of multimedia content (e.g. texts, images, videos, audio). In this perspective, the

FIGURE 4.3: A visitor using the system and a sculpture equipped with a Smart Cricket.

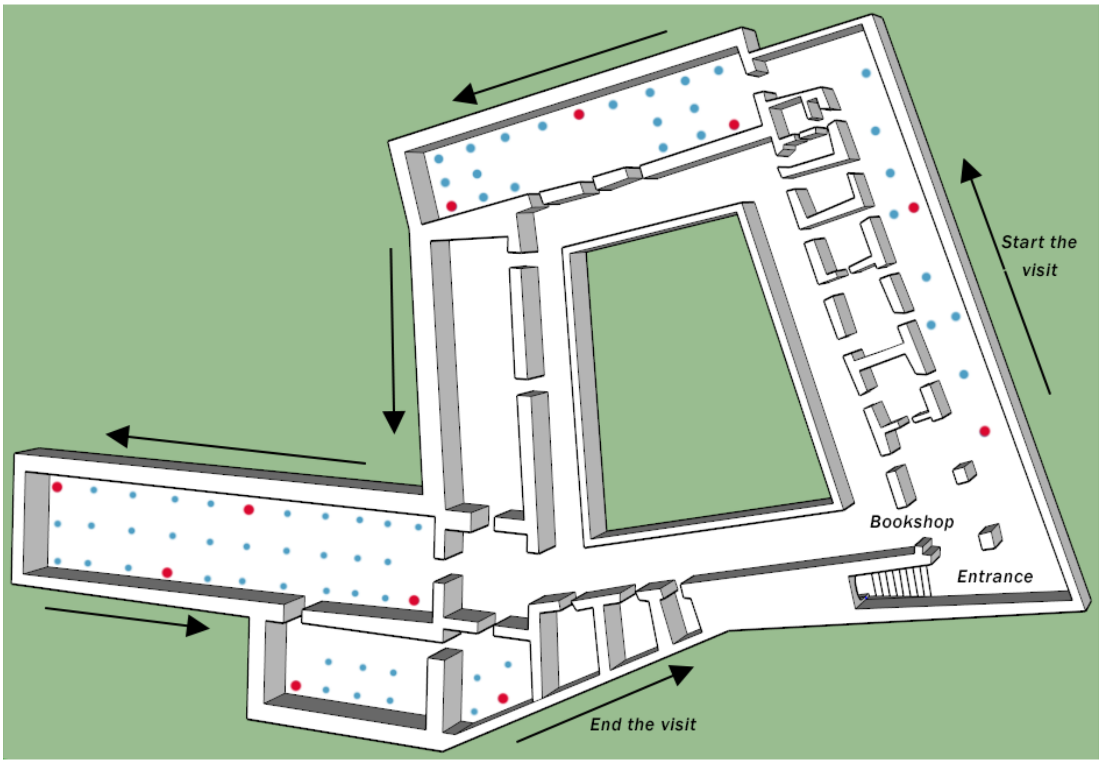

FIGURE 4.4: The exhibition layout: The blue circles represent the SLAVE nodes whereas the red circles represent the SERVER nodes. The arrows indicate the exhibit itinerary.

App, named *OPS - Opere Parlanti Show (The Talking Artwork Show)* is structured with the following main functionalities:

- displaying an art events list; the user can select an exhibition and the application will display a brief summary;

- allowing visitors to access into the exhibit/museum network, in order to enabling the communication process;
- during the visit, the mobile application displays the image of the artwork nearest to the user (he is inside the artwork surrounding area);
- enabling the artwork related multimedia content presentation and supporting the content delivery and enjoyment processes.

The main screens of the OPS application are shown in Figure 4.5. In details, from left to right and from top to bottom, (i) the home screen of the application, (ii) the art events list, (iii) the nearest artworks to the visitor, (iv) the artwork details and insights, (v) the audio story screen, (vi) the image gallery screen, (vii) a detail of a selected image, (viii) a sharing screen where a visitor can share what he is experiencing.

FIGURE 4.5: The mains screens of the OPS mobile application.

4.1.3 Experimental Results

IoT systems are generally complex applications that are based on a combination of several models, algorithms and heuristics. Recently, researchers began examining issues related to user subjective opinions and developing additional criteria to evaluate these systems. In order to evaluate the impact of our system on the user cultural experience we have conducted three experimental scenarios. In particular, the proposed evaluation strategy aims at measuring: (i) *user satisfaction* with respect to assigned browsing tasks in an indoor environment, (ii) *usability, usefulness and satisfaction* with respect to assigned post-visit questionnaires, (iii) how our system can improve the knowledge transmission of a cultural space with respect to a comparison with a pre-existing system.

4.1.3.1 User satisfaction

We designed and carried out several experiments to investigate how helpful the novel fruition metaphor offered by our system is to accomplish assigned browsing activities, demonstrating that the introduction of such techniques can improve the visitors' experience.
In the first experiment, we asked a group of 50 people (15 not-expert users, 15 medium expert users and 20 expert users) to visit a virtual reproduction of the exhibit obtained by the *Unity 3D* framework and complete several browsing tasks (20 tasks per user) of different complexity without the help of our system. After this test, we asked them to browse once again the same collection with the assistance of our system and complete other 20 different tasks of the same complexity. Each task consists in exploring a certain number of sculptures satisfying several constraints. The complexity of a task depends on several factors: the number of objects to explore, the type of desired features (either low or high-level), and the number of constraints (genre, author, subject). In particular, we have subdivided browsing tasks in the following three broad categories:

- **Low Complexity tasks** (T1) - explore at least 20 multimedia objects related to sculptures of the nineteen century exposed in the exhibition;
- **Medium Complexity** tasks (T2) - explore at least 50 multimedia objects related to 5 exhibition sections about Francesco Jerace, Tito Angelini and Saverio Gatto authors. (10 objects for each section);
- **High Complexity** tasks (T3) - explore at least 140 multimedia objects related to 7 exhibition sections about sculptures of (i) the eighteen century, (ii) the nineteen century, (iii) Achille D'Orsi (20 objects for each section).

Note that the complexity of a task depends on several factors: the number of cultural objects to explore, the number of exhibition section to explore and the authors of desired items. Users know each browsing task's goal before selecting target objects. However, if a visiting path initially does not contain sufficiently many objects required by a browsing task, user can modify the path itself changing the list of target objects. The strategy we used to evaluate the results of this experiment is based on NASA TLX (Task Load Index factor) [3].

To this aim, we then asked the users to express their opinion about the advantage of our system to provide an effective user experience in completing the assigned visiting tasks. Thus, we obtained the average results scores for each of three categories of users reported in Table 4.1 (the lower the TLX score - in the range [0-100] - the better the user satisfaction). Note that not-expert users find our system more effective than the other users' category in every sub-scale, because they consider very helpful the provided suggestions. Instead, in expert and medium expert users' opinion, our system outperforms a classical ICT system in every sub-scale except for mental demand and performances: this happens because an expert user considers sometimes not useful the automatic suggestions just because they know what they are looking for.

TABLE 4.1: Comparison between our system and no facilities

	Experts		**Medium Exp.**		**Not Experts**	
TLX factor	**Our system**	**Without**	**Our system**	**Without**	**Our system**	**Without**
Mental	29.7	30.1	35.7	36.5	39	48
Physical	29	33	33	39	34	49
Temporal	31	35.4	30	38.7	32	37
Effort	29.4	35	39.1	46	39	51
Performances	81	74	77	74	78.9	76.1
Frustration	27	37	28.9	34.6	31	34

4.1.3.2 Evaluation of the proximity strategy

The proximity strategy allow to detect both Android and iOS devices but more generally any device which works with Wi-Fi or Bluetooth interfaces. Users' devices could be detected without the need of being connected to an specific Access Point, enabling the detection of any device which comes into the coverage area of a Meshlium base station, but, in the proposed approach, a set of Waspmote sensors nodes are deployed to perform the indoor localization technique. Our choice can be further motivated considering that such devices allow to control the Bluetooth inquiry area with seven different power levels in order to set different coverage zones from 5 to 50m that can be decreased to obtain higher level of precision in detecting users' devices in the artworks surrounding area. The distance of any detected device is calculated exploiting the RSSI value, received

[3]TLX [136] is a multi-dimensional rating procedure that provides an overall score based on a weighted average of ratings provided by users by means of proper questionnaires on six sub-scales: mental demand, physical demand, temporal demand, own performance, effort and frustration. The lower TLX scores (ranging in the 0-100 interval), the better they are.

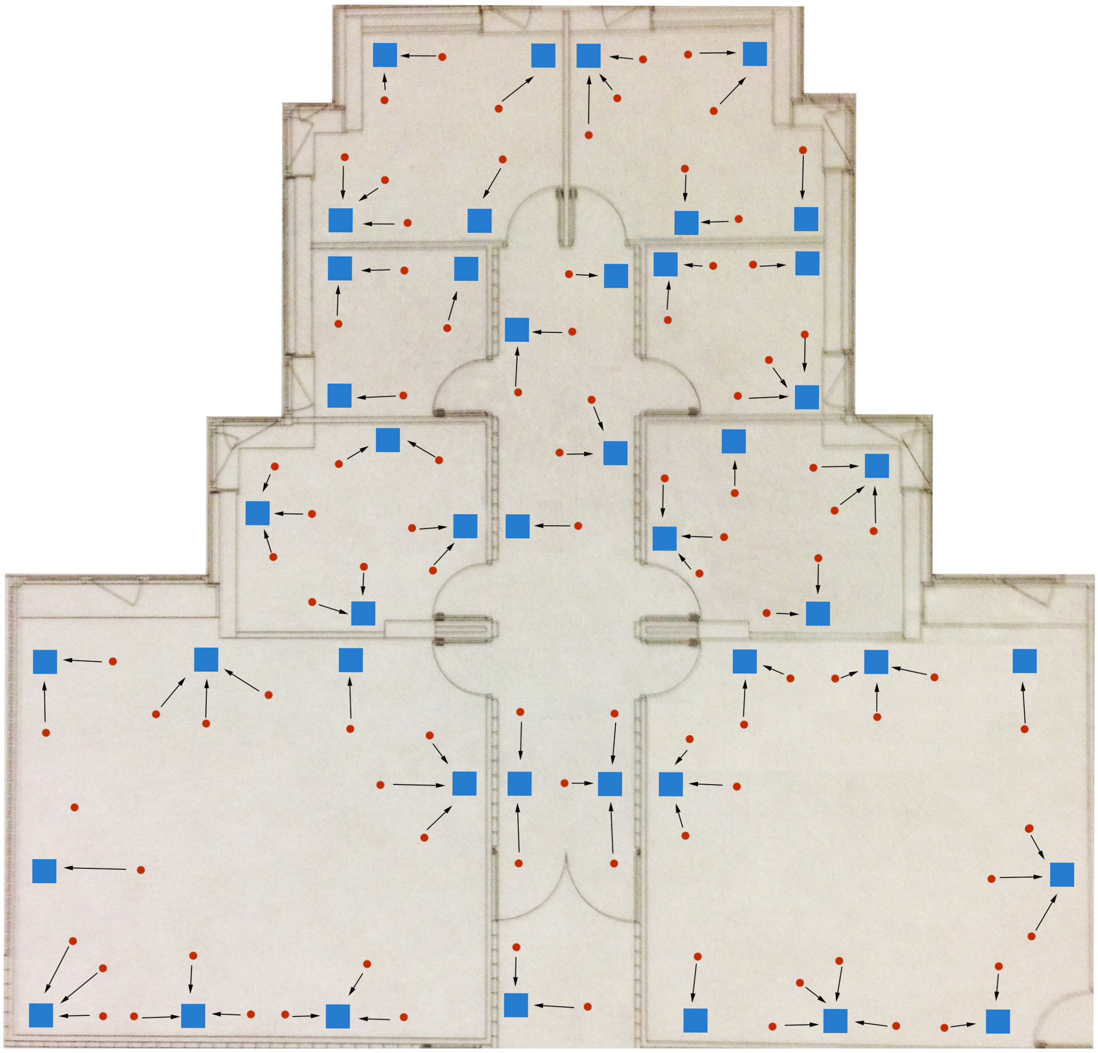

Figure 4.6: Laboratory rooms. Blue squares denote sensor nodes positions, red dots denote user mobile device positions during the measurement campaign and arrows denote directions in which the user is directed.

during the inquiry process slog with the MAC address of the Bluetooth device. RSSI values usually go from -40dBm (nearest nodes) to -90dBm (farthest ones). Laboratory experiments have been performed to assess the behaviour of the proposed proximity strategy; we carried out a measurement campaign on the first floor of our research laboratory. In details, we deployed inside the environment, composed by eight rooms and one hallway, (see Figure 4.6) 45 sensor nodes and tested the proximity solution for 100 different positions of a mobile device, in order to simulate a tourist visit among several exposed cultural items. The distance between a node and the mobile device ranges between 30 centimetres to a maximum of 2 meters. The considered laboratory rooms are typical office environments with different dimensions; it is a harsh environment for wireless communications because of multi-path reflections due to walls and interference due to electronic devices.

The technique described above aims to localize the mobile device closest to the sensor node when inside its surrounding area. The experiments consisted in a set of measures between a sensor-point representing a cultural item and a number of fixed points inside the environment representing possible visitor mobile device positions facing such node. Each measure collected about 1500 RSSI measurements, where each measurement was the average of 25 consecutively received samples. Samples were obtained by sending a beacon packet from the mobile device to the sensor-point at regular intervals, 25 times per second. Overall we collected a total of over 38,500 samples for each of the 100 positions of the mobile device (in a first stage we use an Android Samsung S4 model).

In Figure 4.7, we present the performance results of the proximity system that can be considered as more than adequate. The system has been tested in two different conditions: (i) empty rooms, (ii) rooms with several people inside (about 40 students). Although the data varies between the two different situation, the average of the algorithm determined correct positions exceeds 90% of cases (see dotted lines in Figure 4.7). A position is defined as correct if the nearest object returned by the system is actually the one closest to the user, in other words the user is located in front of that object with the smartphone turned towards it.

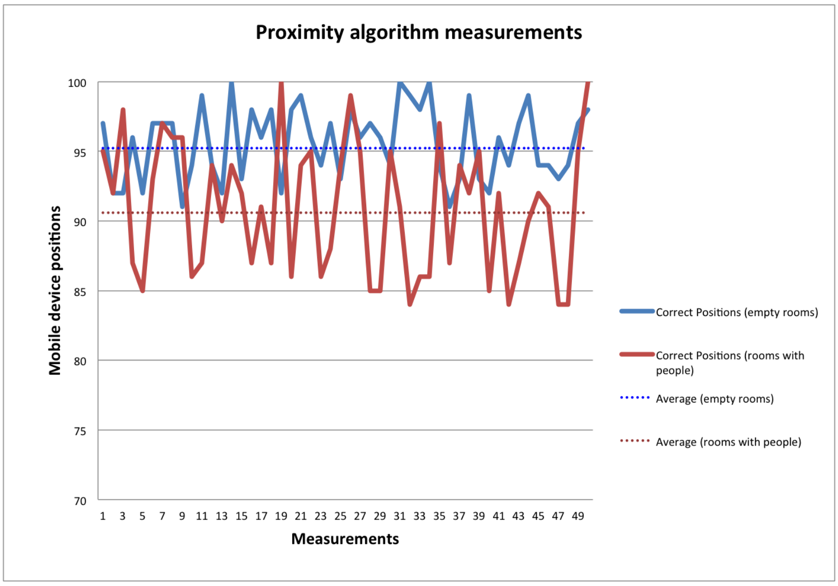

FIGURE 4.7: The measurement campaign: on the x-axis the measurements carried out, on the y-axis the mobile device positions inside the environment.

Since the smartphone market is mainly dominated by devices with iOS and Android operating systems, we designed and compared the proximity system on both kind of OS. Figure 4.8 shows the similar behaviour of the two OS (an Apple iPhone 5 model with iOS 8.1 and a Samsung Galaxy S5 with Android 5.0.1), emphasizing that in both situations over 90% of cases is detected the closer sensor node to the device position. The obtained results indicate that the system performs well in indoor environments in

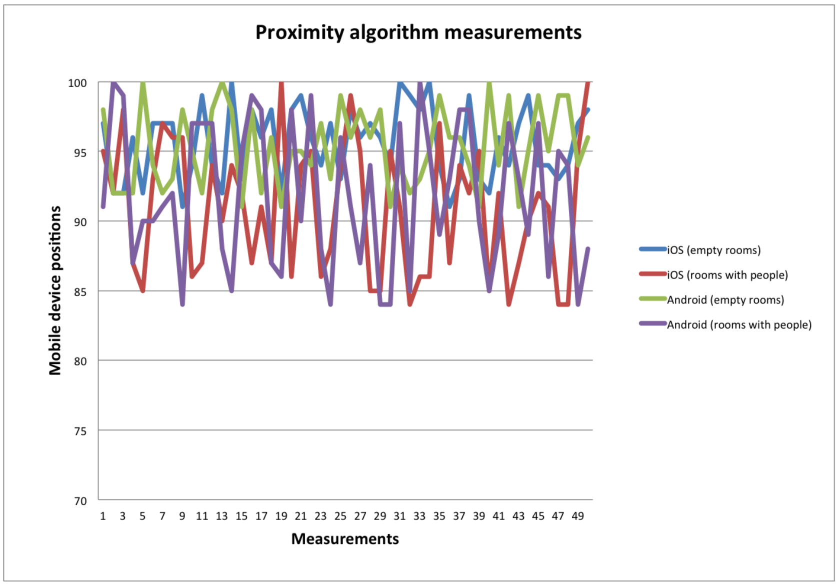

FIGURE 4.8: The proximity system comparison between iOS and Android OS.

the presence of several nodes close together but especially with a high density of people within such environments.

4.1.3.3 Usability, usefulness and satisfaction

A number of trials have been performed to assess the users' behaviour, satisfaction and consequently the usability of the infrastructure in a real scenario. The analysis of user feedbacks is somehow fundamental to correctly designing the multimedia experience. These trials were organized partially by researches in the fields of art and history, who were, together with the our research team, responsible for assisting visitors. The inclusion of knowledge specialists is a fundamental aspect in cultural heritage applications because they can resolve possible conflicts between expert suggestions and automatic recommendations.

In all, 112 volunteers were recruited, 60 males and 52 females of different ages (from 15 to 75 years old). People in the range from 50 to 75 years old reported, in most cases, having a medium-low computer literacy. The 40 % of the participants was under 35 years of age. In order to investigate the usability of the infrastructure, with specific regard to the *ease of use*, *usefulness* and *users' satisfaction* dimensions mentioned by the literature in [139], post-visit questionnaires were submitted to the participants after the trials.

These questionnaires stimulated volunteers to express their level of agreement with a set of statements, using a 10-point Likert scale, or to make choices between options. In addition, to specifically assess the new proposed IoT concept we have selected 32 people from different age and sex to answer few questions about the usability of the system

TABLE 4.2: Assessing the IoT proposal: questionnaire results

ID	**Question**	**Average rating**
IoT1	The proposed technology is ease-to-use.	8.56
IoT2	Accessing to the multimedia information occurs in a reasonable time throughout the exhibition.	8.11
IoT3	The artwork discovery strategy was accurate.	7.93
IoT4	Using this type of technology does not create overload during the cultural experience.	8.28
IoT5	The proposed technology was overall useful.	7.84

from a technological point of view.

Figure 4.9 summarizes the post-questionnaires results and reports the most relevant questions related to the three dimension of our usability framework and their average ratings. The overall degree of satisfaction manifested by volunteers towards our infrastructure was positive with an average rating of 7.43 (SAT9). Multimedia features such as photo-galleries (SAT3), texts (SAT4) and audio (SAT5), were rated 7.77, 7.64 and 7.14, respectively. As for the usefulness dimension, users agreed that the application was useful overall (USN1, 7.88), facilitating to a certain degree the acquisition of a better knowledge (USN2, 7.45) and a deeper insight (USN3, 7.65) on the artwork on display. Additionally, the analysis of the ease of use dimension pointed out that participants found the information access about the artworks quite easy (EoU1, 8.11) and the multimedia content browsing (EoU2, 7.52).

The second questionnaire submitted (see Table 5) indicates that the novel concept we proposed was ease-to-use (IoT1, 8.56). Users agreed that the artwork discovery strategy was accurate (IoT3, 7.93) and the multimedia data can be retrieved in a reasonable time during the exhibition experience (IoT2, 8.11). Overall, most of the answers were found to be consistent (standard deviation in the range [1.55, 2.17]).

To better understand to what extent the technological, user and environmental factors influenced some of the usability dimensions investigated, further statistical analyses were performed. In detail, the analysis aimed at answering the following research questions:

- *Is the user' satisfaction correlated to their familiarity with mobile devices?* Cross-tabulations ($r = 0.632$; $p < 0.001$) indicated that owning tablets or smartphones is correlated to the degree of appreciation manifested by participants (SAT8, ratings above 7). This shows that, despite some limits highlighted by the evaluation, the visitors appreciate the criteria adopted by our infrastructure.

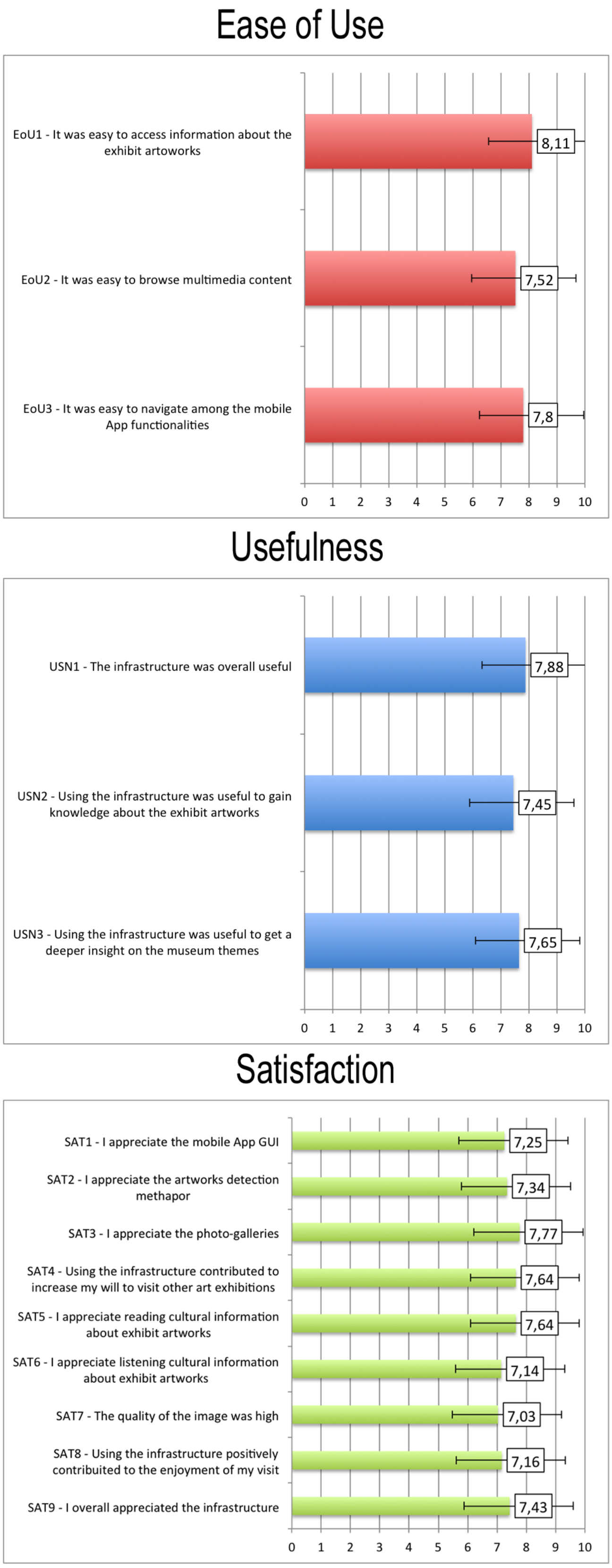

FIGURE 4.9: Ease of Use, Usefulness and Satisfaction results

- *Is the transmission of new knowledge correlated to the enjoyment of the visit?* (USN2, SAT7) The correlation was found significant ($r = 0.641$; $p < 0.001$), suggesting that mobile provided content may play a relevant role on visitors' enjoyment.

- *Is an enjoyable cultural experience correlated to visitors' will to visit other art exhibitions?* Our results ($r = 0.713$; $p < 0.001$) suggests that when the use of the infrastructure contributed to the enjoyment of the visit (SAT7), this also affected visitors' desire to visit other art exhibitions (SAT4).

A further encouraging result, which was obtained through the analysis of the LOG files of the recruited participants, regarding the suggested fruition paths, shows that over 78% of users has completed it entirely and interacted with more than 85% of the artworks suggested. In details, investigating the question IoT3, participants thinks that the implemented proximity technique is able to correctly locate their mobile devices in most cases, as already assessed by experimental laboratory results.
Finally, the users were asked whether they had any problems in using the system and about any suggestions for improvements or general comments on it. The users thought that it could be easier if they could plan a tour beforehand, by using a Web based interface and then retrieve the tour when accessing inside the museum. Users who were domain experts suggested that the system should provide general predefined role associated or similar user profiles or themes that a user could select before starting the visit.

4.1.3.4 Evaluation of the knowledge transmission process

In this evaluation phase, we selected two groups of visitors, respectively of 62 persons (Group A) and 61 persons (Group B). The first group (A) performed the exhibition visit by using our system, the second group (Group B) performed the visit without our system. At the end of the visit, each person of the two groups answered to three questions about the exhibition, in order to assess the knowledge diffusion improvement by using the deployed technological system. The submitted questions are related to the exposed cultural objects:
(1) *What are the names of the three main sculptures' authors within the exhibition ?*,
(2) *What is the material mainly used by the sculptures of this historical period?*,
(3) *What is the theme that links the different sections of the exhibition?* (multiple choice question with three possibilities).

Table 4.3 shows the the questionnaire results; the observed values, assessed by the Chi-Square values, indicates that the use of the proposed system improves the user cultural

TABLE 4.3: Knowledge transmission: questionnaire and Chi-Square results

	GROUP A	*GROUP B*	
Question	Correct answers with our System	Correct answers without our System	**Chi-Square**
1	52	40	5,46 (P<0.005)
2	55	45	4,51 (P<0.005)
3	40	29	3,60 (P<0.005)

experience during an art exhibition, increasing the knowledge diffusion related to the observed cultural items.

4.2 Analysis of visitors' behaviour

In order to classify cultural exhibitions visitors' paths and behaviors, the most popular approach known from the related literature is [141], identifying four types of behaviors compared to four animal categories (Ant, Fish, Butterfly, Grasshopper). The system we are proposing is capable to classify visitors according such well-known animal metaphors, but it focused on the research of indicators more suitable to characterize particular phenomena which appear in the case of strong serial constraints combined with room partitioning.

4.2.1 Test and Experiments

A first experimentation was made during the art exhibition *The Beauty or the Truth*. As mentioned previously, this initiative included both a cultural attraction (sculptures belonging to a specific period of time, with specific philosophical and aesthetic conceptions) and technology-based attractions: "Talking Artworks" , virtual 3D manipulation [142, 143] and exploration of artworks, of and virtual 3D tours through on-site touch-screens. The main source of IoT data was based on smart devices named "crickets" [64, 70, 144]: each cricket monitors an artwork or group of artworks, detects mobile devices in its surroundings, and uses proximity evaluation algorithms to infer the artwork receiving more attention by each visitor at the moment. Then it establishes a dialogue with the visitor through his/her mobile device, and offers a variety of textual and multimedia resources about the specific artwork. Each mobile device must have been previously equipped with an APP downloaded from the Databenc exhibition web site; Databenc also provided tablets for visitors coming without personal devices. Consequently, the many objectives of "Intelligence" on visitor behaviours include another two-fold question: "Tech or Art?", in the sense of estimating whether and when the dominant reason of interest lies in the technological novelty and *divertissement*, or artworks, or both, as well as the general relevance of "multimedia augmentation" of artworks. The cricket-based system collects detailed information during interactions with visitors, and saves Open data in JSON Log files. The identifiers of artworks and multimedia files provide references to a relational database, which stores a rich set of information on artworks including textual descriptions, information on authors, materials and techniques used for their creation and maintenance, catalog tags, grouping of artworks into logical Sections.

4.2.2 On-site ad-hoc visit data processing

In each Log, the individual visit is represented by a Session, which includes multiple Transactions-one for each occurrence of interaction with an artwork; a Transaction encompasses multiple Actions, each one tracking the access to a specific text, image or video file accessed by the visitor through the mobile device. The distances covered by visitors when moving between artworks, in particular using geodesics have been calculated: while in a flat space-time without obstacles or distortions the minimal route between two points is a single, straight line segment, in many exhibitions the possible paths are determined by physical constraints, and in this case the minimal path is more complex. In our exhibition, the rooms could only be traversed following one serial ordering, with at most one minor choice in the ending sections. The algorithm also takes into account the different lengths of each room, and the distribution of artworks along "long & thin" rooms. Our research was focused on indicators more adapt to characterize particular phenomena which appear in the case of strong serial constraints combined with room partitioning. Initial assumptions are easy and obvious to formulate, such as: a) the initial sections receive more attention, and it definitely decreases moving towards the ending sections; b) the limited amount of time which most visitors can devote to a visit can truncate most paths, minimizing the possibility to distinguish different classes of visitors. Hence we tried to capture significant deviations from this scenario, deriving useful indications from them. The analysis of behaviors was articulated at 3 levels of granularity: Section(Room), individual Artwork, Multimedia Contents offered for the Artwork. Among various movement indicators, particular attention was devoted to the following:

- FSKIP: a Forward Skip occurs when the visitor moves forward between Artworks belonging to two non-consecutive sections, skipping one or more intermediate ones; the measure is the number of skipped sections.
- MAXS: is the maximum index of the visited Sections, which identifies the visited Section placed at the longest distance from the exhibition entry point.

Table 4.4: Overall statistics about Multimedia content fruition.

%mm	%uTxt	%uImg	&uAud	%Pause	%Stop
42,52	22,45	8,08	14,76	9,70	52,66

- BACK: a backward movement occurs whenever the visitor moves between two sections in reverse order with respect to the basic route order. This may lead either to a never visited section or to a previously visited one. This measure just counts the final section of the jump and all intermediate sections skipped to reach it.
- LOOP: this occurs when the visitor cycles with multiple Transactions on the same Artwork.
- RETA: Return after alternatives; this occurs when the visitor returns to a Section where he/she already visited at least an Artwork, after having visited one or more other Sections.

The RETA and LOOP measures are collected also at the level of individual Artworks; for each Artwork, at the 3rd level of analysis we measure the time spent for interaction, and the access to Multimedia contents using separate counters for each type (Text, Image, Audio). The overall multimedia appreciation level of a visitor is a weighted sum of these counters, where the weight of Audio files takes into account events such as the pressure of PAUSE and STOP buttons. We then calculate: the number of sections and the number of artworks involved in the entire visit of each visitor j; the length of the total path covered by j as LSj = the sum of the distances covered to visit the Sections; LS= length of the minimal "full path" necessary to cover all Sections with fixed geospatial constraints (1 visit per Section); the "Exhibition Path Completion Level" as $EC_j = LS_j/LS$. When ECj=100%, this means that visitor j covered a total distance equal to 1 full path, while 50% corresponds to a half path, 150% to 1.5 full paths, and 200% to 2 full paths. Other statistics are based on the number of sections and the number of artworks involved in the visit of each visitor. In-depth analysis was conducted on a sample of 246 visitors, which were selected at random ensuring fair coverage of calendar periods and hour slots. This sample is not trivial, considering that another relevant study was based on log files of 140 visitors exploring a frescoed room with a multimedia museum guide [140]. Overall statistics in Table 4.4 indicate that more than 40% of the BoV visitors accessed at least one type of Multimedia Content, Text receives a bit more attention than Audio, which is frequently stopped before its natural end. Images seem to be neglected in advantage of direct observation of 3D sculptures.

However, these statistics are too broad and insufficient for assessing and qualifying the degree of interest raised by the Talking Artwork technology; relevant differences and interpretations emerge only by distinguishing between different classes of detailed behaviors. Thus we performed the PCA (Principal Component Analysis) in order to obtain a reduced set of indicators, on which we applied k-means clustering; exploratory analysis on various graphical distributions (histograms and block charts with 2 or 3 variables) provided further evidences which led to 5 main classes of behaviors, and are supported by explanatory variables with high values of predictive power and confidence (95%-99%). Table 4.5 (Appendix) summarizes the indicators and the intervals which characterize each class, while Figure 4.10 shows the statistical distribution of visitor classes, which can are described in more detail as follows.

A. **HULK**: has the lowest values in multiple measures of attention and appreciation (numbers of visited artworks and sections, multimedia appreciation level), and in most cases truncates the visit after the first two sections. Since the recordings of visits are only based on the usage of mobile devices, we guess that HULK visitors are not fans of this technology, and only try it at the beginning of the visit, just to have a general idea of what it offers;

B. **INVISIBLE WOMAN**: traverses many sections, but leaves minimal or no signs of active presence in most of them, in that the total number of visited artworks is very low, independently of MM contents;

C. **SPIDERMAN**: visits almost all or all sections, as well as a very high percentage of artworks; spends a lot of time with frequent back movements, although the degree of attention paid to MM contents has relevant variations for different artworks;

D. **SUPERMAN**: performs repeated back-and-forth movements between sections, and very often returns to the same artworks; pays extensive attention to the MM contents of some but not all of them; reaches the last Section of the route, but at the cost of skipping some intermediate ones;

E. **IRON MAN**: visits relatively high numbers of both artworks and multimedia contents, but remains within the first 3 or 4 Sections of the route; this appears the class of people having the highest scores of interest for the technological augmentation of artworks.

In summary, from Table 4.5 we observe that the combinations of three indicators (MAXS, number of visited sections, and BACK) appear sufficient to discriminate between classes and predict the other indicators. From Figure 4.10 we note that only the frequencies of SUPERMAN (D) and INVISIBLE WOMAN (B) are significantly lower than the remaining classes, which are almost equally distributed.

Table 4.5: Visitors' Indicators: The combinations of three indicators

	IRONMAN	***HULK***	***SUPERMAN***	***SPIDERMAN***	***INVISIBLE WOMAN***
MAXS	[3-6]	[3-7]	[7-9]	[7-9]	[5-9]
N. of visited sections	[1-4]	[1-2]	[2-4]	[2-7]	[1-4]
BACK	MIX	NONE	ALL	MIX	MIX
RETA	[0-3]	[0-1]	[0-1]	[0.3-4.7]	[0-1.7]
LOOP	[0-10]	[0-2]	[0-2]	[0-10]	[0-3]
N. of viewed artworks	[7-55]	[0-6]	[3-9]	[11-67]	[2-10]
N. of viewed MM content	[7-61]	[0-17]	[1-12]	[0-91]	[0-40]
MM appreciation level	High	[Very Low, Low]	Very High	[High, Very High]	[Low, High]
Exhibition Path Completion Level	[50%-200%]	<50%	[50%-100%]	[50%-200%]	[50%-150%]

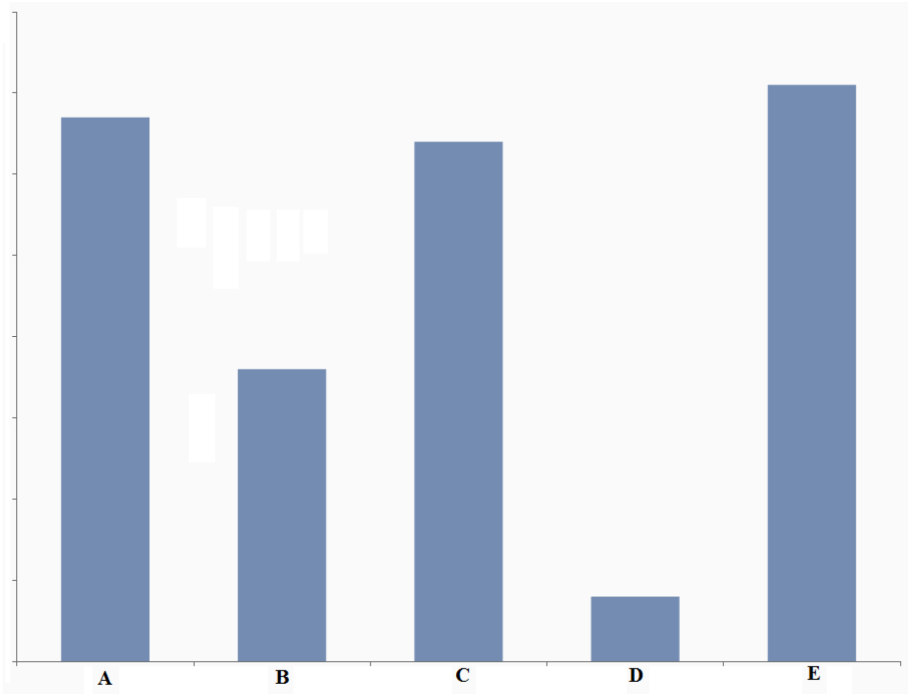

FIGURE 4.10: Distribution of visitor classes.

4.3 Conclusions

As the *Internet of Things* paradigm constitute a powerful tool to address the design of the complex connection between new technologies, knowledge to be transmitted and visitors of Cultural Heritage environments, the gap between the technological reality and the application requirements may be considered the factor which most seriously limits a widespread deployment of ubiquitous solutions in exhibits or museums environments. In fact, there is still more work that has to be carried out to effectively enforce viable, productive and non-invasive applications in Cultural Heritage domain, where heterogeneous devices, environments and people are involved.

As an effort in this direction, this thesis presents an intelligent software/hardware framework which is intended to shorten the distance existing between cultural environments and its visitors, supporting a cultural space mutation with concrete solutions intending to increase people enjoyment and knowledge diffusion. The rationale of this infrastructure's design derives from the need to simplify a context-aware the access to the cultural objects, to their knowledge and connections, of a typical Cultural Heritage indoor scenario, and to ensure that content and technological containers are effective with respect to its end-users. The fundamental role is played by the technology, especially that of WSN and Bluetooth, as a facilitator of the integration between *real* and *digital* dimension in a space that must become *intelligent*. According to this, the technologies cover the role of connector between the physical world and the world of information, in order to amplify the knowledge but also and especially the enjoyment and promotion. In this scenario, the visitor becomes an active element which offer the pleasure of perception and the charm of discovery of a new knowledge, while giving useful information to make more living the space.

For this reasons, our research has been primarily focused on the design of a service-based system providing a set of features to raise the services quality any-time to anyone inside exhibits or museums. Accordingly, our proposal consists of an infrastructure focused on a set of multimedia and location-based services able to support the dynamic building of different, users personalized and customized fruition paths, basing on a retrieval model that select different multimedia content and arrange them in different fruition schema. Specifically, we have introduced a three-tiers, event-based and service-oriented architecture which, through the integration of a Wireless Sensor Network with Wi-Fi and Bluetooth technologies, that yields functionalities to identify, locate and support visitors during a cultural experience.

To assess the behaviour, the performance, the users' satisfaction and the feasibility of our infrastructure, we performed a number of experiments recruiting, in all, 112 participants during a real case study. These experiments were performed during an art exhibition, *The Beauty or the Truth*, located in Naples within the monumental complex of San Domenico Maggiore, Italy. Post-visit questionnaires were used to evaluate the users' satisfaction, system usability, and improvements in the knowledge transmission process; after the analysis of the results, we can assess that visitors had a strong preference for the infrastructure and found it ease to use. The results also indicated that the system can improve their cultural experiences and enhance the transmission of the cultural knowledge related to the environment where the system is deployed.

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