Chapter 3

Using IoT for Accessible Tourism in Smart Cities

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Abstract

In the past few years, the Smart City concept became one of the main driving forces for the transition towards sustainable economy and improved mobility. Tourism, as one of the fastest growing economies worldwide, is an integrated part of the Smart City paradigm. Taking into consideration recent studies performed by the United Nations, stating that almost one third of the population is directly affected by disability, the concept of Accessible Tourism needs also to be integrated in the future vision for tourism, especially in the context of Smart Cities, environments fully benefiting from the recent technological advances. Within the combined framework of Smart Cities and Accessible Tourism, the Internet-of-Things (IoT) concept is the key technological point for the development of smart urban environments. IoT and big data are both technology-driven developments, leading to scenarios such as the Smart Cities one that has the potential to make citizen live smarter, more sustainable and more accessible. This chapter analyses the key requirements for IoT applications in a Smart City context, the state-of-the-art for the use of IoT for Accessible Tourism applications and proposes an architecture together with its practical implementation, tailored for the use-case of accessible tourism for physically impaired persons.

Keywords: Smart Cities, accessible tourism, IoT, route planning

1. Introduction

In the last few years, the IoT concept emerged as the forerunner of a sweeping technical and cultural change with a fast growing number of devices, sensors, actuators and various other objects becoming linked to each other and to upper-level systems [1]. Considering the potential very large amount of connectable devices and generated data, completely new features and services can arise that can constitute the basis for various innovative concepts, as for example, Big Data and Smart Cities. The latter concept has the potential to make citizen lives smarter and more sustainable and, at the same time, to create extended market opportunities.

The Smart Cities architectures implemented or designed up to date are tackling with use cases from the following use cases: transportation, energy, environmental management and waste disposal. The specific architectures for these use cases rely mainly on IoT platforms connecting heterogeneous devices and systems with the upper layers where services and applications are implemented [2]. Among the aforementioned use cases, transportation is of particular interest, taking into consideration that tourism is currently the largest growing economy branch worldwide. Without transportation -local one included- there is little or no tourism, so the development of tourism is tightly linked to the concept of mobility which, for the specific case of an urban environment, can be included in the frame of the Smart Cities paradigm.

Recent estimations state that there are more than 1 billion persons with disabilities worldwide, to be summed to other more than 2 billion representing the spouses, children or caregivers of the persons with disabilities, for a total of almost a third of the population directly affected by disability [3]. While this signifies a huge potential market for the aforementioned economic branches of travel and tourism, it still remains vastly under-served due to inaccessible travel and tourism facilities and services. The concept of accessible tourism [4] is an enabler for all categories of people to be part of and to enjoy tourism. Each person can have a specific access need, related or not to a physical condition. A typical example is the one of older and less mobile persons, that come with specific needs for traveling or touring activities. The concept of accessible tourism is starting to gain importance in order to enable destinations, products and services to all people, independently from their physical limitations, disabilities or age [5]. The changes induced by this new concept can affect public and private tourist locations, facilities and services. From idea to the practical implementation of a trip, a single destination visit normally involves many factors, including accessing information, local transportation, accommodation, shopping, and dining [5]. For these reasons, it can be stated that the impact of the implementation of the accessible tourism concept can reach far beyond the specific case of tourism, adding accessibility to the social and economic values of society [3, 6].

Putting together the previously mentioned elements, this chapter aims, to offer an overview on IoT requirements and technologies for Accessible Tourism applications in a Smart City environment, and to propose a specific architecture together with a practical implementation tailored for the use case of accessible tourism. The proposed implementation is targeted for persons with physical impairments or special access needs.

The content of the chapter is structured as following: the next section analyses briefly the key requirements for an IoT architecture operating in a Smart City environment for the specific implementation; Section 3 presents an overview on the use of IoT technologies for accessible tourism, while Section 4 is dedicated to the proposed general IoT architecture. Section 5 describes the accessible tourism solution based on the optimization algorithm presented in Section 6, while Section 7 presents a series of simulations. Section 8 presents the conclusions and the future work.

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2. Key requirements for IoT-based Smart City environments

The Smart City concept has many definitions and implementation approaches. However, from an infrastructural point of view, all Smart Cities have at their core a highly capable ICT system, in the form of an IoT platform, connected to wired and wireless sensor networks. The hardware and communication part, together with advanced data analytics that settle the basis for developing intelligent applications and services for citizens [7]. Still now, even after some years of functionality, the key requirements for the requirements for IoT platforms operating in a Smart City scenario are difficult to define.

A forerunner of architectural designs is the PROBE IT EU-financed project having as main aim to benchmark IoT deployments and to set the guidelines for IoT roll-outs for Smart Cities [8]. Using some of these guidelines, considering various other surveys [9–12] and consulting the requirements fulfilled by some of the existing commercial IoT architectures and platforms [13, 14], we extracted a set of key requirements tailored specifically for accessible tourism applications in the Smart City context.

2.1. Security requirements

By the year 2020, worldwide there will be 50 billion connected devices [13], accounting for a mean value of 6 devices pro capita. IoT platforms aggregating data imply that these devices can be accessible over the Internet. Data networks, especially poorly configure ones, are vulnerable to all kind of attacks. IoT environments, always connected to the Internet, are not at all different, therefore there is the need for solid security mechanisms, which, specifically for a Smart City environment can be summarized in the following form:

1. *Data encryption and security mechanisms:* In most of the cases, data is more vulnerable when it's in transit using cabled or wireless transmission methods because most of the services encrypt data only when it gets to the data center. The challenge here is to enable end-to-end security by making the entire authentication happen without the user's intervention, so the data encrypts automatically at the source.

2. *Hardened cloud infrastructure:* Hosting data in the cloud can be far more secure than keeping in a data center but the cloud infrastructure may be also subject to attacks. ISO 27001 is a security certification standard that specifies security management best-practices and controls for data centers and cloud environments.

3. *Activity logging:* For both developers and users, activity logging is an important part of the intrinsic security of an IoT platform. Especially in a Smart City environment, and specifically for the present use case with large amounts of sensor data triggering certain actions, logging is critical for monitoring the functionality of the platform and to contrast possible malfunctions and security breaches.

2.2. Flexibility

The IoT market is still in its early stages of adoption, as it is also the case for the Smart City concept. The next generation of connected devices and products needs to rely on a certain software flexibility and for these reasons, an IoT platform in a Smart City environment should comply with following flexibility rules [15]:

1. *Device agnosticism:* The changes in the configuration of a device should be limited to updating the driver and at maximum the data format when adding or updating a devices, allowing hardware developers to develop their new generations of products without being limited by legacy or compatibility issues.
2. *Device manageability:* An inherent characteristic of a Smart Cities deployment is that the devices and sensors are placed at large distances in a Smart City environment, the IoT platform has to include methods for the remote management of devices.
3. *Usage of open APIs:* The devices and sensors present in a Smart City context inherently generate large amounts of data. It can happen that a conspicuous amount of this data remains not analyzed due to its unavailability to other users than the ones originally intended. The IoT platforms should therefore allow the access to shareable data, becoming like this a true motor for future innovative applications.

2.3. Data requirements

The data in the IoT world comes mainly from things but can also arrive in the form of metadata from users. IoT and Smart Cities are more than a sink for incoming data, data intelligence being the key concept. This implies relatively strict requirements in terms of data [13, 14]:

1. *Data processing and analytics services:* An IoT platform's usefulness is given by its ability to process the collected data and turn it to usable information.
2. *Data scalability:* Especially in a Smart City environment the amount of IoT data has the tendency to grow fast, for example when monitoring environmental data. The IoT platform should therefore have the necessary features in order to manage the data using archiviation and culling methods, preferably fully automated.

3. Overview on the use of IoT technologies for accessible tourism

In the last decade, Travel Recommendation Systems (TRSs) have benefited from the Information Communication Technology (ICT), which has become the main source of information for the tourists, assisting them in choosing services around them [16]. As the technology makes its way into the fabric of everyday life, it become easier even for people with disabilities to take advantage of TRSs.

In particular, the IoT, as an enabler technology, can offer people with disabilities the assistance and support they need to achieve a good quality of life and allows them to participate in the social and economic life. In [17], the authors propose an IoT architecture to assist people with disabilities and envision some application scenarios where such users can benefit from the IoT, such as during shopping, at school or in a domestic environment. They claim how the IoT can

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make easier for people with some kind of impairments to carry out their daily activities and then increase their autonomy and self-confidence.

However, despite the rapidly increasing number of tourists with disabilities, both the tourism industry and the scientific community has paid little to no attention to find solutions to facilitate and make their tourist experience more enjoyable, due to the assumption that this group of people is usually not interested in traveling [18].

The few works analyzing the needs of people with disabilities aim to understand which can be their stimuli to travel; in [5], for example, the authors research the criteria consumers with disabilities regards as being important to their choice of accessible accommodation; similarly, the work proposed in [19] deals with understanding how tourists with mobility disabilities make decisions to choose accessible travel products.

Nevertheless, even if there are several solutions which apply the IoT paradigm to sustain and manage tourism (smart tourism scenarios), little work has been done to offer assistance and support to people with disabilities. In [20], the authors underline the strict correlation between smart city and smart tourism conceptualizations and the focus on public service models at the expense of comprehensive and systematic exploration of its business opportunities and implications. In [21], several possible smart tourism scenarios are presented: from services to help select destinations and search suitable travel arrangement to services that provide on-site support to the tourist during the trip helping her/him to discover nearest places of interest. Another example is proposed in [22], where the authors propose an agent-based system; such a system enables to model different kinds of activities in a flexible way, and allows the implementation of location-aware applications.

Finally, in [23], an IoT solution for sustainable tourism has been proposed and applied to a specific Smart City scenario. The authors take into account two main elements in order to propose the best set of Point of Interests (PoIs) for the tourist, namely the choice of the transportation mode and the information regarding the queue time expected at each PoI. Even if no implementation has been provided, simulated results show how such an approach based on the IoT paradigm can increase the tourists' satisfaction.

To the best of our knowledge, in this chapter we go for the first time beyond the state of the art, by proposing a solution to apply the IoT paradigm to accessible tourism for people with disabilities, in which cruise ship tourists, with limited available time, wants to maximize their tourist experience.

4. Proposed architecture

As mentioned in Section 1, in this work we introduce an IoT platform suitable for a Smart City environment and applied to the sustainable management of the tourist flow in the city of Cagliari, Sardinia's capital, which is one of the two biggest island in Italy and one of the most attractive point for tourism, especially in summer. In such a scenario, we envision that, through the use of virtualization technologies, each object in the real world is associated to its virtual counterpart in the cloud. This is a common practice in the latest IoT research efforts [24], since the virtualization of the physical devices enhances their capabilities, making the objects capable to: (i) describe their characteristics with semantic technologies in order to be able to interact with other virtual objects; (ii) identify, analyze and manage the context of the object's surroundings, taking the decision accordingly; (iii) facilitate the search and discovery of devices and services, continuously joining, moving across and leaving the network.

4.1. Proposed architecture

The proposed platform relies on the Cloud IoT architecture [25], named Lysis, organized on four distinct levels (**Figure 1**). Service discovery and information exchange do not need objects to be in vicinity of each other, since they take place in the virtual world through the exploit of social relations.

In the following the four levels as described in details: the highest level is the *Application Layer* in which user-oriented applications are deployed; the *Service Layer* is responsible to receive the application requests and map them to the atomic services available in the lower layer; this layer is the *Virtualization Layer*, which interfaces directly with the real world and enhances objects' functionalities; the last level is the *Real World Layer*, containing the real physical devices of the Smart City. Two additional cross-layers are needed to manage the quality requirements of the applications and to ensure that every communication takes place in a trustworthy and secure way, according to the previously listed requirements.

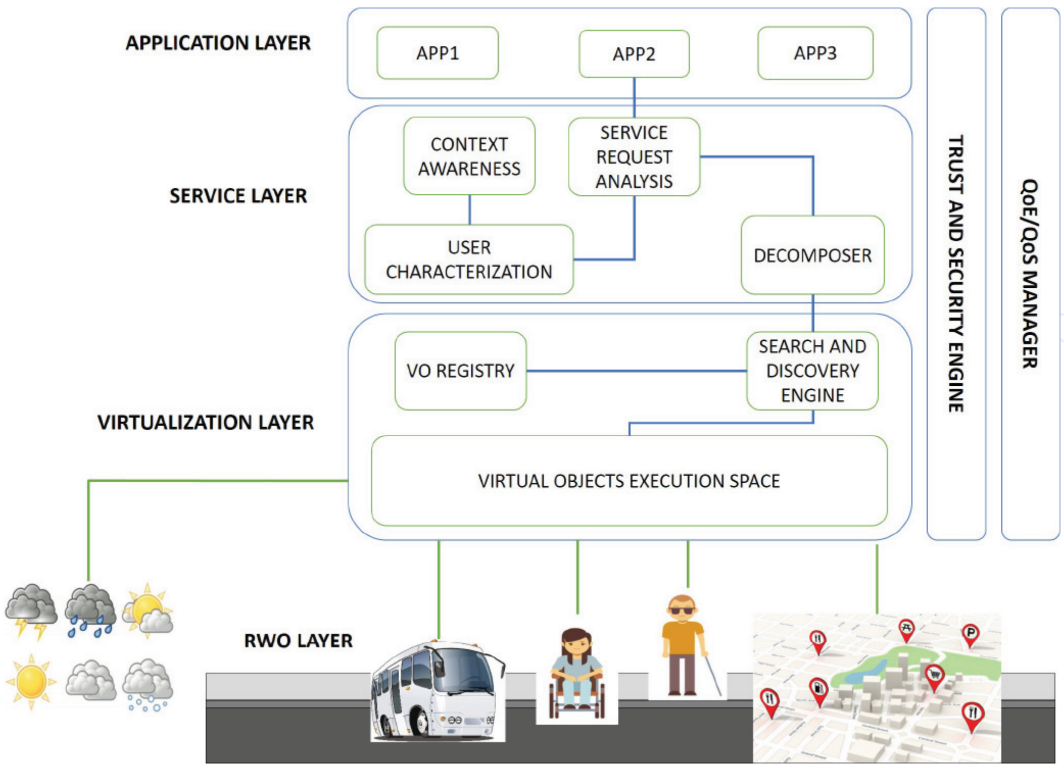

Figure 1. Cloud-based IoT architectural solution.

This approach has manifold motivations: (i) it enables objects to speak the same language at the virtual level; (ii) it enhances the service search and discovery; (iii) it decouples the service requests and the actual IoT objects which satisfy the request and (iv) it offers personalized experience to users based on their own needs and traits.

In the following paragraphs, we describe in detail the layers proposed for the architecture.

(1) *Application layer:* This is where user applications are deployed. Each application is composed of two interfaces: a front-end interface, which represent the access point for users or objects to interact with the system, and a back-end interface, which connects this layer to the rest of the platform and enables the application to be fulfilled by the lower layer.

(2) *Service layer:* At this level, service requests are analyzed and augmented with a range of facts concerning the human user, including user context, the type of disability, his/her profile, the preferences in terms of PoI categories and security policies.

The *Service Request Analysis* (SRA) receives the query from the Application layer and interact with the User Characterization block to obtain information regarding the user and the context in which the query has been made.

In particular, the *User Characterization* (UC) includes all the knowledge the system has accumulated regarding each user interacting with the system and his/her preferences. This block has then the ability to complement the query with additional information so that each application is truly personalized based on the user. This is an important component in our platform because many applications in a Smart City scenario, such as the one for sustainable tourism, are characterized by personal choices: requests coming from different users can have different solutions. This is particularly true for the use case of disabled persons, posing new constraints in the SRA that have to be taken into account when solving the query.

To have a broader view of the user, the UC block alone is not enough. This is due to the fact that the UC only accumulate static information, and does not take into account the specific situation the user is involved in. This is the role of the *Context Awareness* block, which considers the context in which the query has been made. For example, a tourist with a certain disability looking for a museum to visit, can receive different recommendations based on the accessibility of the structure, the time of day, the possible routes to reach it, the presence of uphills and downhills, the distance from other museums or the number of people in the queue waiting to visit it.

Finally, since an application is composed of one or more services, there is the need of a *Decomposer*, which collect the information obtained by the other blocks in this layer and decide which atomic tasks (sensing, actuation, computational) are needed to fulfill the query. Then, it forward a group of subqueries for the Virtualization Layer.

(3) *Virtualization Layer:* This layer is responsible for virtualizing the sensor (& actuation) data *for* any service needs, which is stored in a related database. Objects and devices of the real world are represented digitally in this level in the form of *Virtual Objects* (VOs) and their offered services are described in terms of semantics.

To overcome the limited capabilities of the IoT objects, in the virtual world the VOs enhance their capabilities and enable them to perform additional operations. White canes, i.e. canes for blind or visually impaired people, wheelchair but also museums, parks or busses can communicate among them without any problem at this level even if they all use different communication technologies: simple technologies, such as RFID tags and NFC, can be attached to Points of Interest (PoIs) to enhance the visiting experience of tourists by interpreting information about the environment and making choices accordingly, for example by pushing additional information regarding the PoI to users [26].

To activate a new VO, the system has to find a match between the possible VO templates and the information (metadata) provided by the physical device; such information comprehends: objects' characteristics; objects' location; resources, services, and quality parameters provided by objects. When a match is found, a new instance of the object is created (i.e. the web server representing the VO itself), which run in the *Virtual Object Execution Space* (VOES), where all the instances of VOs run.

Each VO has two interfaces: the first one enables the VO to create a standardized communication procedure with the physical object; this way, the VO can communicate with the object using a set of different protocols based on the situation at hand. The other interface allows the VO to "speak" with all the other VOs in the VOES; thank to this, it is possible even for physical objects with have different communication technologies to communicate among them and become interoperable at the virtual level.

The VO registry stores a semantic description for each active VOs in the VOES, in the form of metadata, which is then used every time there is the need to search for a particular VO.

This metadata is particularly useful in the case of accessible tourism, where the information regarding the different objects available for people with disability needs to be described with the correct metadata in order to be easily discoverable; this is the case for example of busses with a platform for tourists in a wheelchair or of museums which provide audio guides for visually impaired tourists.

When the *Search and Discovery Engine* is activated by the upper layers, it search in the VO registry to find any potential available VO that can match the query, i.e. any VO whose metadata can match the services required.

(4) *Real-World Object Layer:* Implemented out of the cloud, this level includes every device that is capable of *accessing* the Internet. These devices are called Real World Objects (RWOs) due to their direct connection with the physical environment where they sense and act.

(5) *Trust and Security Engine:* This layer focuses on the implementation of appropriate security procedures to guarantee that attacks and malfunctions in the platform will not outweigh any of its benefits. At the Virtualization level, for example, this plane needs to understand how the information provided by the VOs have to be processed so as to build a reliable system on the basis of their behavior. In the Application level, the Security Engine could determine the accessibility of the different applications to grant access only to authorized users.

(6) *QoE/QoS Manager:* The management of quality is an important issue in classical IoT implementation mainly due to the heterogeneity of the objects and to their mobility. In the proposed platform, we address these problems making use of VOs; however, even with

the adoption of virtual counterparts, in order to monitor the overall level of the applications, both from a communication point of view (Quality of Service) and from a user point of view (Quality of Experience), a quality manager is still needed.

5. Proposed accessible tourism solution

This section presents an accessible solution designed on top of the IoT platform presented in the previous section, aiming to provide useful information to tourists in general, with particular attention to the ones with special needs. The application has been developed for the cruise ship tourists who land in the city of Cagliari, but it could be applied to many Western European tourist destinations, regardless of the means of arrival (i.e. plane, train, or ship).

5.1. Cruise tourism

When arriving in Cagliari, many cruise ship tourists, often prefer to take a walking tour rather than taking an organized tour. After getting off the cruise ship, these people have to spend too much time to get the needed information about programming their visit. And time is a very critical aspect for cruise ship tourists, due to the limited number of hours the cruise ship usually stays at the call port. This aspect gets worse for disabled people, depending on the type and degree of disability. In the case of mobility disability, for instance, a destination like Cagliari, where reaching the most important attractions require a lot of walking uphill, due to the natural and geographical features of the city, many tourists are constrained to limit their visit to the areas around the port. Instead, with some detailed information about accessible routes in the city, more tourists could reach all the attractions of interest within walking distance of the port getting a better experience from their visit. This is why we designed and developed a mobile application dedicated to generic tourists and specifically adapted to accessible tourism. In case of physical impairments, this mobile application is capable to optimize visits to specific mobility user needs. In this work we adopt the paradigm of people inclusion and universal access to information and tourism assets.

In the recent years, tourism experiences of people with disabilities have largely been a research key topic [27]. Research results have been focused on accessible tourism and accommodation preferences [5]. Most of the available tools are based on web sites for travel planning with focus on inclusive tourism such as Tur4All (https://www.tur4all.com/) and Jaccede.com (https://www.jaccede.com/). Specific tools face just single aspects of the problem. LinkedQR [28] is a tool to improve the collaboration between QR codes and Linked Data, through mobile and Web technologies. Nevertheless, the role of IoT in tourism is expected to create innovative experiences for consumers [29].

There is a lack of tools specifically designed for everyone and able to perform specific outcomes for disabled. Our application addresses this challenge, following the paradigm of whole-of-life to tourism, considering that 30% of a population will have access requirements at some stage during their life [4].

5.2. The tour planner application

The Tour Planner is a mobile application, useful to build a dynamic itinerary through a city, based on a repository of Points of Interest (PoIs), each one of them is represented as a VO on the platform (**Figure 2**).

The Tour Planner application is developed on top of the proposed platform, and it takes in input not only the Points of Interest related to monuments, museums, archeological sites, parks, botanical gardens, shopping areas, restaurants, but also commercial offers and events as well as every information that can be important for the user, such as his/her particular needs, the length of the queue in real time from the PoIs or the weather.

Moreover, the Tour Planner allows to save the itineraries built by the end users (the tourists) in a format suitable to be saved in the platform, then making it available for other users. The information available on the platform are regularly taken and stored (updated) in the back end of the mobile application. The mobile application has been developed with the Ionic Framework in order to be suitable for any mobile platform.

The platform takes all the information about the Points of Interest (PoI) in a certain geographical area. The PoIs are stored in the platform according to a classification related to the type (the already mentioned, monument, museum, archeological site, etc.).

5.3. How the tour planner works?

The Tour Planner aims to improve accessible tourism because it provides the possibility to build itineraries suitable for people with disability, adding detailed information about the accessibility of each Point of Interest, whenever available. Unfortunately, a well-known problem is related to the fact that most of the web sites based on the Points of Interest paradigm do not follow standards like the "ISO 7001:2007 Graphical Symbols" (https://www.iso.org/obp/ui/#search/grs/7001). Although not comprehensive, these standards are suitable to notify tourists

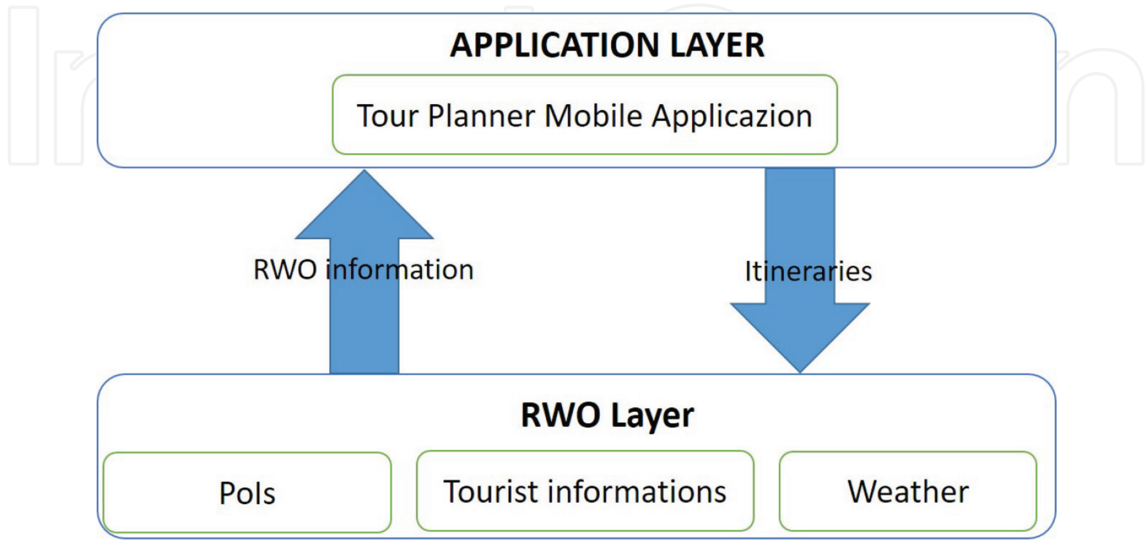

Figure 2. The RWO and the tour planner exchange information each other.

about the existence of facilities for disabled people. The information would be complete if also the "not existence" of the facilities would be reported (in a standard way, as well). Another issue in relation to this aspect is that quite often the presence of these facilities is not compliant to standard like the ISO 21542:2011 for building construction - Accessibility and usability of the built environment (https://www.iso.org/obp/ui/#iso:std:50498:en).

Some disability rights organizations periodically (for instance, yearly) verify if declared accessibilities are compliant to the standard. As a good example of this, in UK, there are important providers of access information like DisabledGo (https://www.disabledgo.com/). If this kind of verified information could be automatically collected and stored in the platform, the Tour Planner application would be able to acquire them and to build proper itineraries accordingly. In our case, a further improvement should come from the municipality of Cagliari by providing access infrastructures through the streets of the historical city, and making the related information available.

In this accessible destination scenario, a disabled person, for example with a limited degree of mobility, could use the Tour Planner application to properly construct his or her tour, including the PoIs and the routes that connect them, depending on the needed level of accessibility.

Obviously, the presented Tour Planner application represents only a technology which allows this scenario of accessible destination to become reality; in fact, the solution requires some effort by the decision makers in order to make all the actors of the scenario to co-operate for realizing it (**Figures 3** and **4**).

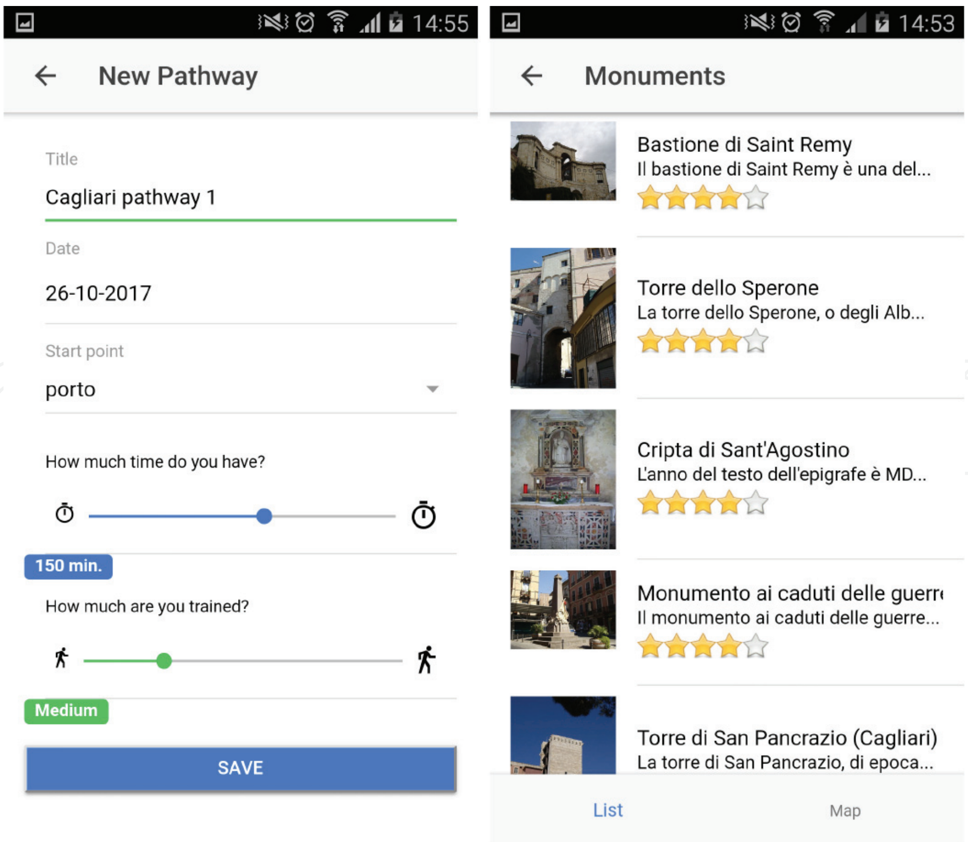

Figure 3. The tour planner set up and the list of PoIs.

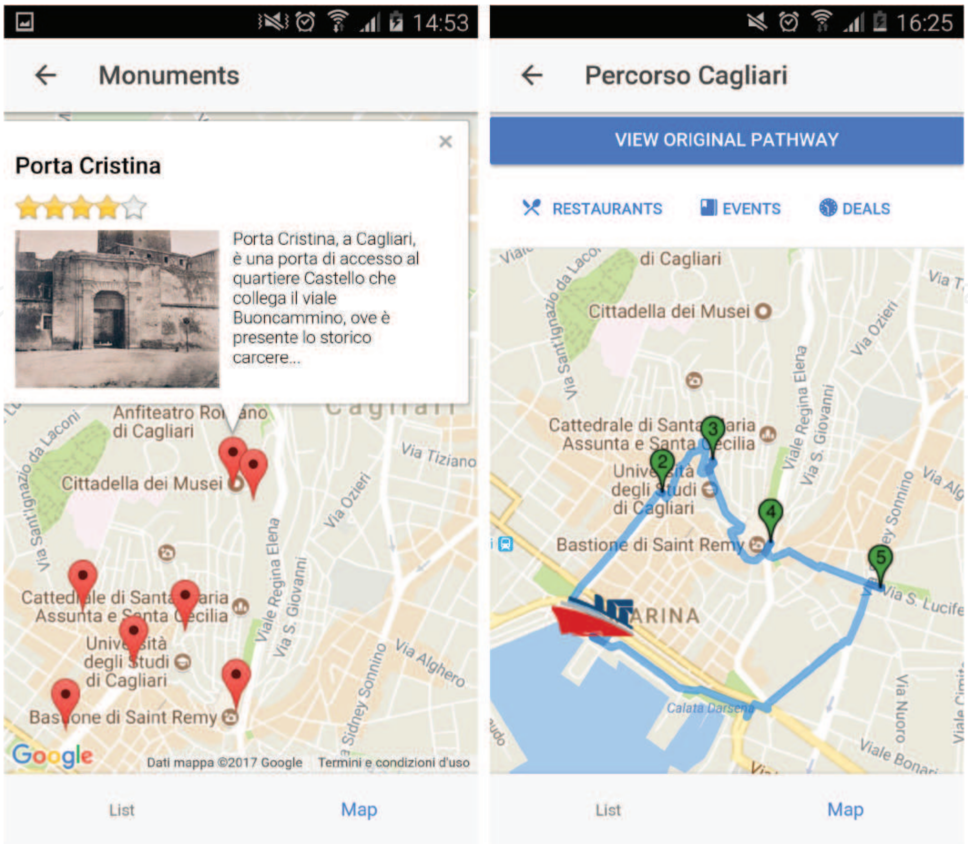

Figure 4. The map showing the PoIs chosen by the tourist (on the left), and the optimized itinerary (on the right).

The aim of the Tour Planner application is to make the visit of a destination accessible for everyone, addressing the described critical aspects through the following features:

1. The tourist defines the total amount of time he has to visit, his physical training level with respect to available paths, and the type of preferred attractions.
2. The application shows a list of most important Points of Interest, sorted according to the information described in 1.
3. The tourist can select each Point of Interest to get more information, including those related to accessibility, and then has the possibility to choose what to see during the visit.
4. The application connects the Points of Interest selected and optimizes the resulting path producing a tour suitable to the tourist.

6. Optimization modeling

Two optimization models are implemented to plan the tour of tourists. In the first model, a subset of PoIs is selected in order to maximize their attractiveness. In the second model, an optimal tour among this subset of PoIs is determined by solving a Traveling Salesman

Problem: the tourist is given an optimal route where he/she visits each POI only once, minimizing the cost of moving between the selected PoIs.

6.1. First model

We consider the current location 0 of the tourist and a set I of POIs. A time interval d can be spent at most to visit a number POIs from the current location. Each POI is associated with a ranking p_i representing its attractiveness for tourists and a visiting time v_i.

The problem can be described as the following graph theoretic problem. Let $G(N, A)$ be a direct and complete graph, where N is the node set and A the set of arcs connecting nodes of set N. Nodes correspond to the points of interest and the current position of the tourist, i.e., $N = I \cup 0$. Arcs represent possible connections between two distinct nodes. Let $t_{i,j}$ be the time to move along arc $(i,j) \in A$ and M a large positive constant.

The following decision variables are defined:

- $X_{i,j} \in \{0, 1\}$ is equal to 1 if the tourist moves along arc $(i,j) \in A$, 0 otherwise;
- $Y_i \in \{0, 1\}$ is equal to 1 if POI $i \in I$ is selected for the visit, 0 otherwise;
- $U_i \in \{0, \dots, |N|\}$ is the position of POI $i \in N$ in the current trip.

The problem can be formulated as follows:

$$Max \sum_{i \in \mathcal{J}} Y_i \cdot p_i \tag{1}$$

$$\sum_{j \in \mathcal{J}} X_{0,j} = 1 \tag{2}$$

$$\sum_{j \in \mathcal{J}} X_{j,0} = 1 \tag{3}$$

$$\sum_{j \in \mathcal{N}, j \neq i} X_{j,i} = \sum_{j \in \mathcal{N}, j \neq i} X_{i,j} \quad \forall i \in I \tag{4}$$

$$\sum_{j \in N, i \neq j} X_{i,j} = Y_i \quad \forall i \in I \tag{5}$$

$$U_j - U_i - 1 + M \cdot \left(1 - X_{i,j}\right) >= 0 \quad \forall (i,j) \in A \tag{6}$$

$$\sum_{i \in \mathcal{J}} Y_i \cdot v_i + \sum_{(i,j) \in A} X_{i,j} \cdot t_{i,j} \leq d \tag{7}$$

$$X_{i,j} \in \{0, 1\} \quad \forall (i,j) \in A \tag{8}$$

$$Y_i \in \{0, 1\} \quad \forall i \in I \tag{9}$$

$$U_i \in \{0, \dots, |N|\} \quad \forall i \in N \tag{10}$$

In (Eq. (1)) one maximizes the ranking generated by the selected POIs. According to (Eq. (2)), a PoI must be visited after the current location. Constraints (Eq. (3)) enforce for the tourist to come back to the current location after the visit of the last PoI. Constraints (Eq. (4)) guarantee that a tourists arriving at any PoI must also leave from that PoI. Constrains (Eq. (5)) link decisions variables on POIs selections and movement between nodes. Constraints (Eq. (6)) are the subtour elimination constraints of Miller, Tucker, and Zemlin. Constraints (Eq. (7)) enforce that the overall time spent to move between nodes and visit POIs is lower that the planned time interval. Finally, (Eq. (8)), (Eq. (9)), and (Eq. (10)) are the domain of decision variables.

It is worth noting that one does not have to visit all nodes of the N, unless a large value of d is considered. Moreover, the direct graph makes very easy to model the case in which starting and arrival points are different.

6.2. Second model

Consider the subset $\overline{N}$ of nodes selected in the previous model. These nodes may not be visited in an effective order, as this model does not aim to minimize the costs of movement between nodes. To correct this drawback, we consider a second model, in which a formulation of the Traveling Salesman Problem (TSP) is presented. The solution of the TSP determined the so-called *optimized itineraries* mentioned throughout this paper.

The TSP can be described as the following graph theoretic problem. Let $G(\overline{N}, \overline{A})$ be a direct and complete graph, where $\overline{A}$ the set of arcs connecting nodes of set $\overline{N}$. The following decision variables are defined:

- $X_{i,j} \in \{0, 1\}$ is equal to 1 if the tourist moves along arc $(i, j) \in \overline{A}$, 0 otherwise;
- $U_i \in \{0, \ldots, |\overline{N}|\}$ is the position of POI $i \in \overline{N}$ in the current trip.

The problem can be formulated as follows:

$$Min \sum_{i \in \overline{N}} \sum_{j \in \overline{N}} t_{i,j} \cdot X_{i,j} \tag{11}$$

$$\sum_{j \in \overline{N}, j \neq i} X_{i,j} = 1 \quad \forall i \in \overline{N} \tag{12}$$

$$\sum_{j \in \overline{N}, j \neq i} X_{j,i} = 1 \quad \forall i \in \overline{N} \tag{13}$$

$$U_j - U_i - 1 + M \cdot (1 - X_{i,j}) >= 0 \quad \forall (i, j) \in \overline{A} \tag{14}$$

$$X_{i,j} \in \{0, 1\} \quad \forall (i, j) \in \overline{A} \tag{15}$$

$$U_i \in \{0 \ldots N\} \quad \forall i \in \overline{N} \tag{16}$$

In (Eq. (11)) one maximizes the ranking generated by the selected POIs. According to (Eq. (12)) and (Eq. (13)), a node must be visited before and after the current one, respectively. Constraints in (Eq. (14)) are the subtour elimination constraints of Miller, Tucker, and Zemlin. Finally, (Eq. (15)) and (Eq. (16)) are the domain of decision variables.

7. Results

In this section we show the viability of the proposed tools to support the mobility of physically disabled tourists or elder persons. We also analyze the case of able-bodied tourists for the sake of comparison. The difference between the two cases is shown by increasing travel times along uphill and downhill routes for disabled tourists as opposed to able-bodied ones. The experimentation is carried out in the city of Cagliari, where many tourists disembark from cruise ships at the harbor. They typically aim to visit the oldest part of Cagliari, which is known as the Castello. It clings to the slopes of a hill that rises steeply from the harbor. Therefore, in this case study it is of particular relevance to distinguish between the waking times of disabled and able-bodies tourists, in order to properly plan which subset of PoI should be visited, as well as the order of the visit.

Four classes of PoIs are considered, which correspond to different profiles of tourists interested in museums, monuments, gardens or shops. We took their location and their altitude from the open data platform and we derived the average slope of the streets connecting PoIs. The average travel time per unitary distance was calibrated by a sample of tourists with similar disabilities over a set of streets with different slopes. Since the distance between all PoIs is known, we easily derived the travel times among them.

All the PoIs are ranked with a value ranging from 1, less attractive, to 5, most attractive. A subset of PoIs is considered for each class by a score threshold, which specifies the PoIs the tourist wants to visit. For example, if it taken on value 2, we consider all PoIs with a score bigger than or equal to 2. We initially set the score threshold to 3 and relax the constrain on (7) and compute the itineraries for each class of PoIs. In **Figure 5** the time to visit all PoIs is reported for all class of PoIs in four cases:

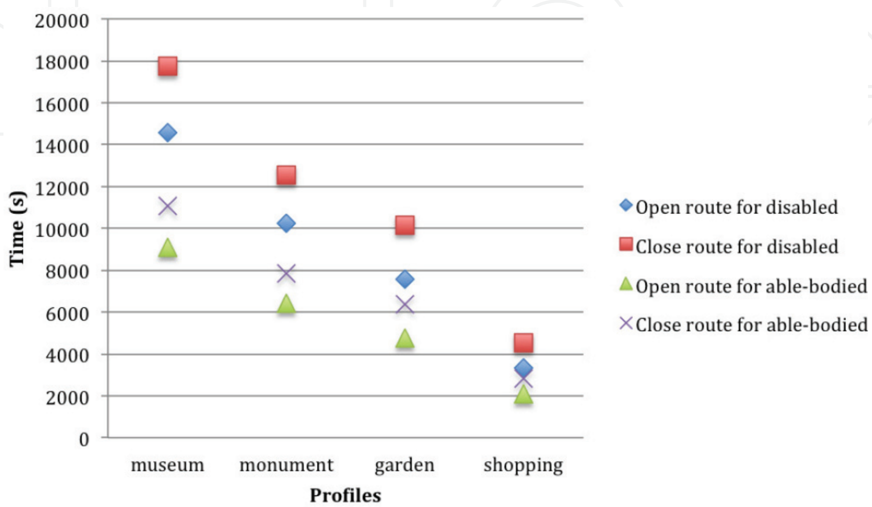

Figure 5. Minimum time for optimized itineraries with threshold = 3.

- Open itineraries of disabled tourists from a given GPS location to the port (blue rhombus);
- Closed itineraries of disabled tourists leaving and returning back to the port (red square);
- Open itineraries of able-bodied tourists from a given GPS location to the port (green triangle);
- Closed itineraries of able-bodied tourists leaving and returning back to the port (gray cross).

As expected, it takes longer to make closed itineraries than open ones and the overall visiting time for disabled tourists is larger than that of able-bodied ones. Next, we reintroduce constrain (Eq. (7)) and plan itineraries according to settings of the time limit *d* and score threshold. More precisely:

- In the results of **Figure 6**, *d* is set to 120 min and the score threshold to 3;
- In the results of **Figure 7**, *d* is set to 240 min and the score threshold to 3;

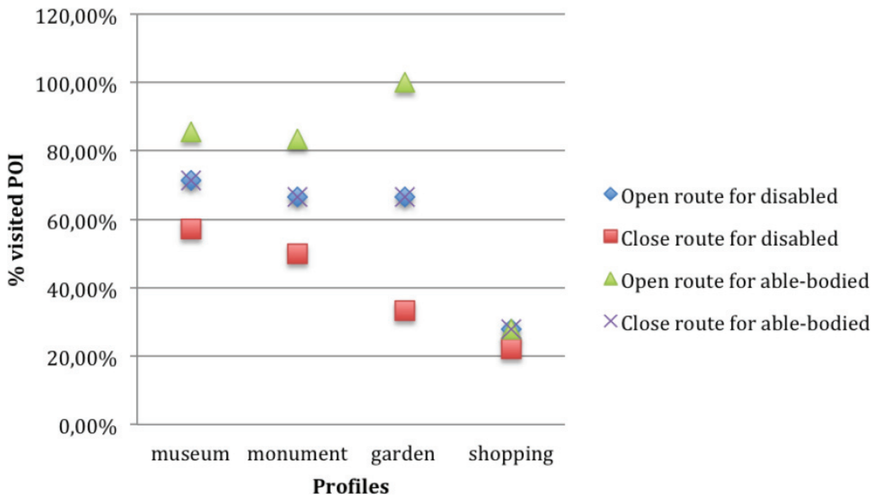

Figure 6. Optimized itineraries with maximum time 120 min and threshold = 3.

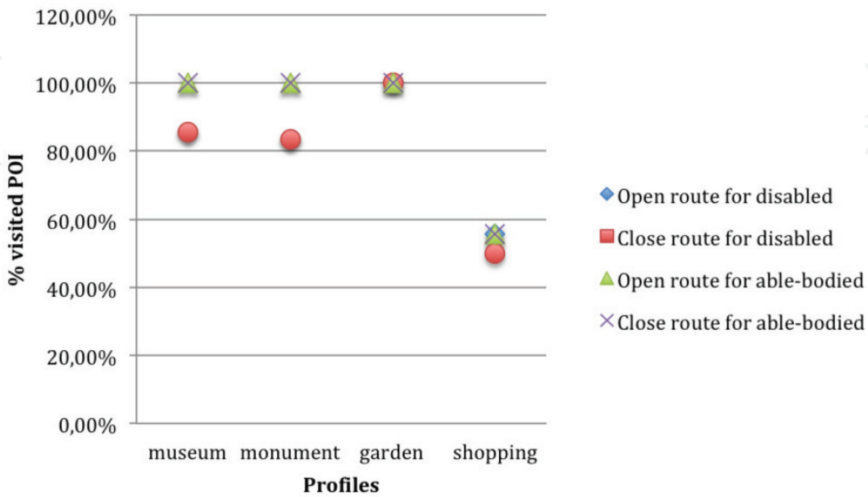

Figure 7. Optimized itineraries with maximum time 240 min and threshold = 3.

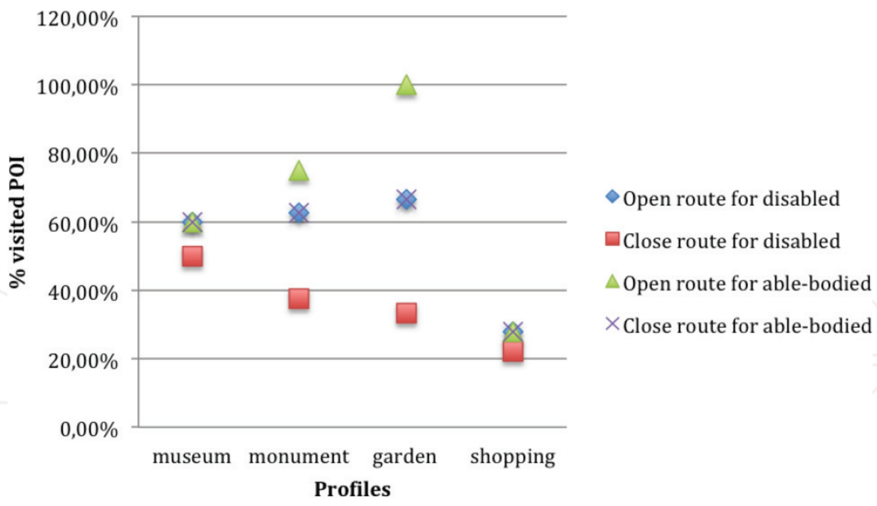

Figure 8. Optimized itineraries with maximum time 120 min and threshold = 2.

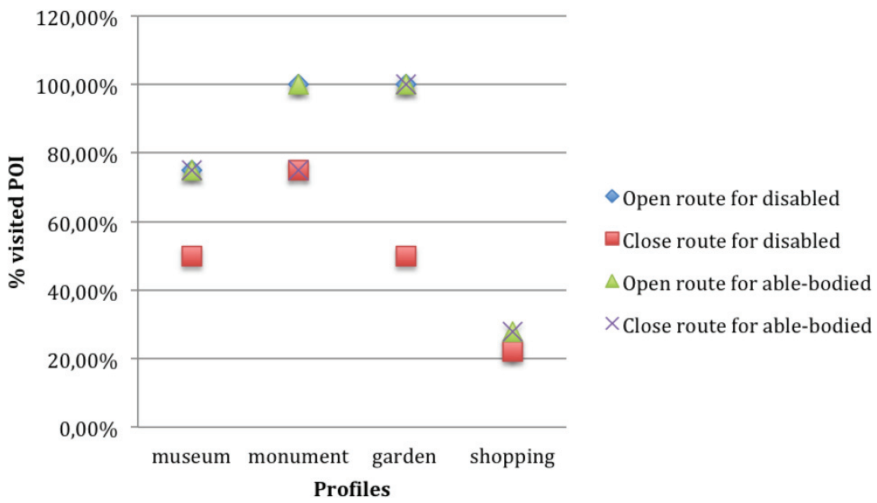

Figure 9. Optimized itineraries with maximum time 120 min and threshold = 4.

- In the results of **Figure 8**, d is set to 120 min and the score threshold to 2;
- In the results of **Figure 9**, d is set to 120 min and the score threshold to 4;

The obtained results show that the proposed tools can be customized to return a subset of PoIs for physically disabled tourists as opposed to the set of routes determined for able-bodied persons.

8. Conclusions and future work

Within the framework of Smart Cities, Accessible Tourism and Internet-of-Things (IoT), this paper analyses the key requirements for IoT applications in a Smart City context, the state-of-the-art for the use of IoT for Accessible Tourism and presents an IoT architecture for the specific Smart City scenario dedicated to the sustainable management of the tourist flow in the urban environment of Cagliari. Based on the presented IoT architecture, a Tour Planner Application with features for accessible tourism is presented, together with the mathematical optimization model used for generating a specific tour including a subset of PoIs. The proposed application is tailored for persons with physical impairments. The results of the initial tests are presented and first conclusions are drawn. The obtained results showed that the proposed algorithm can be customized to return a subset of PoIs for disabled tourists as opposed to the set of routes determined for able-bodied tourists. The future work will be focused on refining the used algorithm by taking into considerations new accessibility constraints and also other types of input, such as for example live accessibility data from public transportation.

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