ISCTE IUL

Instituto Universitário de Lisboa

Department of Information Science and Technology

An Intelligent System for Interactive Visits in Smart Places

Bruno Miguel Filipe Costa Coitos

A Dissertation presented in partial fulfillment of the Requirements for the Degree of
Master in Computer Engineering

Supervisor
Nuno Miguel de Figueiredo Garrido, Assistant Professor,
ISCTE-IUL

Co-Supervisor
Carlos José Corredoura Serrão, Assistant Professor,
ISCTE-IUL

September 2019

Abstract

In this work, we designed and developed a prototype as an integrated system to provide visitors or users of complex buildings, such as museums, hospitals, shopping malls, amongst others, relevant information in an interactive and comfortable way while keeping it simple and affordable for the building managers. To achieve this, a mobile application was developed that allows its users to access information from several Smart Places, in a single mobile application. This application has a generic and common interface to be used by different types of Smart Places and provides multi-language information, to the end-users, that can be defined and translated by each Smart Place. To make this possible, the prototype architecture was designed providing the Smart Places independence since they have their own database and can manage their information. Furthermore, the system uses an Indoor Location and Tracking System taking advantage of BLE devices and Bluetooth capabilities of mobile devices to provide the relevant and interactive information based on the end-user location within the Smart Place. This prototype is also composed of an open-source Content Management System (based on Drupal 8), that allows the system operators to upload and manage the information provided to the end-users. Since the design and construction of most modern buildings go through a BIM process, our Content Management System provides a way to upload information extracted from BIM tools through CSV files. The resulting system is affordable for Smart Places while being comfortable and interactive for the users.

Keywords: Indoor Location System, BLE, Mobile App, Smart Places, Beacon, BIM.

Resumo

Neste trabalho, foi desenhado e desenvolvido um protótipo sendo um sistema integrado de forma a proporcionar aos visitantes ou utilizadores de edifícios complexos, tais como museus, hospitais, centros comerciais, entre outros, informação relevante de forma interactive e confortável, mantendo-o simples e acessível para os gestores de edifícios. Para tal, foi desenvolvida uma aplicação móvel que permite aos seus utilizadores aceder à informação de vários Smart Places, numa única aplicação. Esta tem uma interface genérica e comum para ser utilizada por diferentes tipos de Smart Places e disponibiliza informação multilingue, aos utilizadores, podendo ser definida e traduzida por cada Smart Place. Para que isto seja possível, a arquitetura do protótipo foi desenhada de forma a garantir a independência dos Smart Places, uma vez que estes têm a sua própria base de dados e podem gerir a sua informação. Além disso, o sistema utiliza um Indoor Location and Tracking System, aproveitando os dispositivos BLE e os recursos Bluetooth dos dispositivos móveis, para fornecer as informações relevantes e interativas baseadas na localização do utilizador dentro do Smart Place. Este protótipo também é composto por um Content Management System de código aberto (baseado no Drupal 8), que permite aos operadores do sistema carregar e gerir as informações fornecidas aos utilizadores finais. Como o planeamento e construção dos edifícios mais modernos passam por um processo de BIM, o Content Management System permite carregar informações extraídas de ferramentas BIM através de ficheiros CSV. O sistema resultante é acessível para Smart Places mantendo-se confortável e interativo para os utilizadores.

Palavras-Chave: Sistema de Localização Interna, BLE, Aplicação Móvel, Smart Places, Beacon, BIM.

Acknowledgments

I would like to thank my supervisor, Professor Nuno Garrido, for always being available to help me, closely following the course of this dissertation and always giving the necessary support for its development. To my co-supervisor, Professor Carlos Serrão, that from the first moment proved to be available to guide me and had an important role in the decisive moments of this dissertation, always presenting constructive criticism. To both, a special thank for all the effort they had in the initial phase of this dissertation, making contacts with several places in order to be able to implement and test the prototype resulting from this dissertation.

To my mother and father, Lurdes e Jorge, I thank them for all the words of support and strength they have given me throughout my academic journey and also for all the effort they have always made to give me the necessary conditions to achieve my goals. To my grandparents, Manuela e Manuel, thanks for their understanding in the moments when I could not be present and for all the support they gave me unconditionally. A special tribute to my aunt Lucília, who despite her special needs always gave me her unconditional love, and although she could not have been present until the end, it was an additional strength during the course of this dissertation.

To my girlfriend, Patricia, I would like to thank all the strength and motivation that she gave me in the moments when I needed it most. I also thank my friends for the support and suggestions they gave me during the execution of this dissertation.

Finally, to the IoT Department of ISCTE-IUL, I thank for providing the beacons so that I could use them in the prototype tests.

Contents

List of Figures

List of Tables

List of Acronyms

API – *Application Programming Interface*

BIM – *Building Information Modeling*

BLE – *Bluetooth Low Energy*

CMS – *Content Management System*

CSV – *Comma-Separated Values*

GPS – *Global Positioning System*

ILS – *Indoor Location System*

IoT – *Internet of Things*

ISCTE – *Instituto Superior de Ciências do Trabalho e da Empresa*

IUL – *Instituto Universitário de Lisboa*

QR – *Quick Response*

RFID – *Radio-frequency Identification*

SDK – *Software Development Kit*

SIG – *Special Interest Group*

UWB –*Ultra Wide Band*

Wi-Fi – *Wireless Fidelity*

WLAN – *Wireless Local Area Network*

1. Introduction

We are currently witnessing an increasing flow of people to urban areas, whether for professional or leisure purposes. This means that cities must adapt to meet the growing needs of their inhabitants or visitors and therefore there is an increasing number of larger and more complex buildings. This type of buildings, together with the diverse needs of its visitors/users, makes it necessary for the building managers to provide more information, in a more detailed and explicit manner.

This dissertation consists of the research and development of an integrated system that allows managers of large and complex buildings to make them comply with some of the paradigms of Smart Places, thus providing their users with relevant information to help them to take full advantage of services in these spaces. The proposed system, which includes a mobile application, aims to make it possible to present valuable information in a clearer and more relevant way, using the location of the user within the building or place, while keeping it simple and affordable to manage the information and maintain the system.

1.1. Motivation

The number of people living or working in urban areas has increased and this trend is expected to continue [1], so there is a growing urge for bigger and more complex buildings to satisfy all of their needs, e.g. hospitals, shopping malls, museums, sports facilities, amongst others. The managers of these buildings or sites, or any other controlled open space, have the challenge to provide relevant information to the users/visitors, and this is often done using guiding plates which are a very limited and inefficient way of doing it. If we consider large and complex buildings, such as hospitals, it is common for users to get lost and have trouble finding their way around, requiring additional information in multiple formats and languages.

Mobile devices have become ubiquitous to everyone transforming themselves into interaction gateways between the digital and the physical world [2]. One of the areas that

have benefited most from the use of this type of technology has been tourism. Visitors use their mobile devices to get more information about what exactly they visit and also to improve the way they visit the cities monuments or facilities. One of the areas of tourism that can greatly benefit from the use of these technologies is Museums and Exhibitions.

According to the data collected from 405 Portuguese museums by the Nacional Statistics Institute in 2016, national museums had 6.7 million foreign visitors in a total of 15.5 million visitors [3].

Therefore, by making the visits more interactive and improving the visiting experience, it is possible to create a better attraction both for local and foreign visitors, and the mobile devices can be a flexible and efficient approach for this quest and a preferable way to display relevant information.

On the other hand, if each building or site has its own mobile application to help its users, it makes it necessary to install several applications on the mobile device if a person wants to visit/use several buildings. For example, if a person wants to visit five buildings, he would have to install five different applications on his mobile device, which can cause discomfort and usability problems.

1.2. Objectives

The objective of this work is to research and develop an integrated system aimed at providing relevant information, based on the users location, of multiple buildings or sites in just a single application whilst removing the need for multiple complex applications with different layouts and behaviors to be installed on the end-user mobile device. This integrated system consists of two different main components: (a) a smart and interactive mobile guiding application (MOG – My Own Guide), that uses an Indoor Location System (ILS) based on information provided by Bluetooth Low Energy (BLE) beacons and (b) a Content Management System (CMS) module, which gives the building managers the capability to easily create and modify the information displayed to the users via the mobile application whilst gathering valuable information about the interaction of the users when inside the building.

Considering that complex buildings, sites or other spaces, can have lots of zones and points of interest, loading all this data into the prototype using only a CMS is not only unfeasible but also hugely time-consuming. Therefore, we considered this as an opportunity to integrate our prototype with a tool that could have this information or parts of it, already configured. Nowadays, modern institutional or private buildings go through a Building Information Modeling (BIM) process, using tools that allow the creation of 3D models of any building or site with information about the building, spaces of the building, such as rooms, and any other relevant information. Therefore, we decided to provide an efficient and fast way for the Smart Place staff to upload files extracted from BIM tools. This can speed up the data creation process since by using the BIM, the building managers can define the relevant information needed to our prototype, that can be the interest zones, groups of interest points and interest points, as well as their location in the building and then upload the files to the CMS which in turn can map this information to the objects defined in the data model.

1.3. Outline

This dissertation is organized in five main chapters, structured in order to present each phase of this work.

The introductory chapter of this dissertation presents the problem addressed and reference the motivation and objectives of this dissertation.

In the following chapter, referring to the analysis of the state of the art, we start it with a section where we make a general description of the Smart Places concept, which is the central topic of this dissertation. In the next section, the concept of Indoor Location System is addressed, as it is an important point for the creation of Smart Places aimed at providing relevant information based on the user's location, where we make a study of the main approaches used. Next, we address the modeling using BIM, since it is a process that is currently widely used in the construction of buildings. After that, we present our research results of the available databases, presenting our choice based on the prototype needs. Then, we present some facts obtained during our research on Content Management Systems (CMS), as well as some conclusions on the chosen CMS. To finish this chapter, we present some related works, making a comparison between them, and finish with some initial conclusions.

The third chapter refers to the architecture of the designed and developed prototype, which is divided into five sections, where we describe each component of the architecture.

In the fourth chapter, we approach the system validation, where we perform an analysis by case study, using two examples, namely a Smart Museum and a Smart Mall, where we make a summary of the benefits that the prototype can bring to each one of them. We finish this chapter with a comparison between our prototype and the works mentioned in the state of the art.

Finally, the main conclusions after the development of this dissertation and suggestions for future work are presented.

2. State of the Art

In this chapter, we first address the concept of Smart Place, which is a central concept of this dissertation. Next, the concept of Indoor Location System is presented, and we discuss some existing systems currently in use, addressing their advantages and disadvantages. After this, there is a section about Building Information Modeling and how it is used nowadays. Next, we present a section where we describe and discuss available databases, which we later use to define which one to use in our prototype. Then, we present some results of our research for Content Management Systems and the reasons for our choice. We finish this chapter with two sections, where in the first we present related works that we have found during our research and in the last section we make a comparison between the related works and take some conclusions.

2.1. Smart Places

One relevant concept that is important to explain is the concept of "Smart Place" [4]. Since there are Smart Museums, Smart Campus, Smart Mall, Smart Restaurant, Smart Store, and many others, we used the concept of Smart Place to mention all those different places in a generic way. So, each Smart Place is a physical area that has sensing capabilities (through the usage of multiple sensors) [4] and allows the interaction between people and the physical place. In our work, we take advantage of IoT devices to create and assign different tags inside Smart Places that can be detected by the end-users mobile devices when in the vicinity of the sensor.

This concept can be used in a variety of places and situations. One of the possible use cases is in museums. A Smart Museum can be much more appealing to visitors than a common Museum, since it can provide information taking into consideration the location of the visitor, thus suppressing the need to read the information placed physically in each area, which sometimes can be very limited.

Another relevant use case is shopping malls that can also be considered as Smart Places. This way it is possible to promote existing stores, or even advertise specific products or promotions within each store, whilst taking into consideration the physical location of the visitors.

2.2. Indoor Location System (ILS)

To create a Smart Place and be possible to track the location of the mobile users, it is necessary to have an Indoor Location System (ILS). In this section, we explain the most common systems used for Indoor Location, based on Triangulation and Proximity techniques [5].

The Triangulation technique consists of inferring the position of a person taking into consideration three fixed and known points. On the other hand, the technique of Proximity infers the position based on physical contact or capturing a signal of small range transmitters.

2.2.1. Global Positioning System (GPS)

The first system we approach is the Global Positioning System (GPS) [6] that uses the Triangulation technique. This system takes advantage of a minimum of 24 satellites (see Figure 1) and each broadcasts a signal with information about the current position, orbit and the exact time. Then the receiver combines the information from multiple satellites and calculates the exact position.
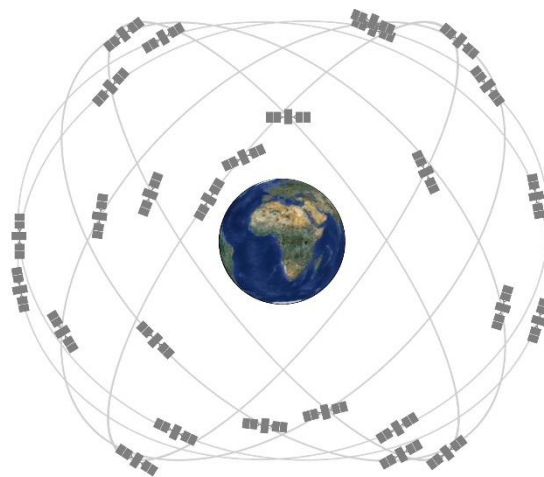
Figure 1 - GPS satellite constellation [7].

This system, if used under open sky and considering a GPS of a smartphone, has an accuracy within five meters radius, however, this accuracy is worse when the receiver is near or inside a building, so this system is not recommended for Indoor Location.

2.2.2. WiFi

The WiFi technology can also be used to create an Indoor Location System and since that it is present in almost every building, it can have the benefit of not bringing many additional costs, especially in hardware.

For tracking purposes, this technology has two main methods that are the Received Signal Strength Indication (RSSI) and fingerprinting [8].

The RSSI combined with the trilateration method allows to calculate an approximate indoor location, since the RSSI of a WiFi signal "is a measurement of how well your device can hear a signal from an access point or router" [9], being inversely proportional to the distance, and the trilateration uses the distance from at least three fixed points to calculate the position.

The fingerprinting method can increase the RSSI accuracy, since it uses historical data to determine the location, but has the disadvantage that if we have a space with objects that are not fixed, there is a need to update the historical information every time that the location of an object is changed.

2.2.3. QR Code

The QR (Quick Response) [10] code is a 2D barcode (see Figure 2) based on the Proximity technique, and can be easily scanned and read by most mobile devices equipped with cameras. This code can store information in text format that can be used to store many different types of information.

The fact that there is no need for extra hardware is a big advantage but, on the other hand, this system requires the user to start the interaction, meaning that the user must read the QR code with the mobile device.

Figure 2 - QR code with "ISCTE"

2.2.4. Radio Frequency Identification (RFID)

Another system based on the Proximity technique is the RFID, that uses waves of radiofrequency to transfer data. With this system, it is possible to define tags and assign them to items in order to be later identified, which depending on the type of RFID, can be read in a range between a few centimeters to more than twenty meters [11].

For the RFID transmissions, the three primary frequency ranges used are Low Frequency, High Frequency and Ultra-High Frequency. In [11], the main disadvantages mentioned for Low and High Frequency are the short read range and low data transmission rate.

Near Field Communication (NFC), commonly used in payments and transport ticketing, is one of the technologies that use the Ultra-High Frequency RFID, which has two types of tags: Passive and Active.

Passive RFID tags can only send data and do not have an internal power supply, but instead, are powered by electromagnetic energy transmitted by an RFID reader while active RFID can send and receive data and use battery-powered tags that continuously broadcast their own signal [12].

2.2.5. Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) [13], developed by the Bluetooth Special Interest Group (SIG), is a wireless technology that compared to the classic Bluetooth provides better energy efficiency while keeping a similar range of communication. This technology is supported by the main mobile operating systems including Android and iOS.

To use this technology is necessary to place BLE devices, such as beacons [14] (see Figure 3), and in order to detect their signals it is necessary to use a specific protocol that can be:

- IBeacon [15] – Developed by Apple;
- Eddystone [16] – Developed by Google.

Besides those, some SDK's are developed by beacons vendors, based on internal technologies to provide more services, *e.g.* Proximity SDK [17] developed by Estimote [18].

Figure 3 - BLE Device (Beacon)

2.2.6. Comparison

In this subsection, we make a comparison between the Indoor Location Systems mentioned above, which helped deciding which of them best fits our prototype.

One important point to our decision is the cost since we want to build a prototype that can be affordable for most Smart Places, but also that has good accuracy to guarantee that we can provide the correct and relevant information for the end-users.

In [19], the authors also made a comparison between Indoor Location Systems and presented a table with the results, based on the following categories:

- Tracking Accuracy: location precision provided by the device;

- Maintenance Effort: cost and human effort in maintenance and updating the equipment;

- Industry Uptake: how quickly the ILS is acquired by customers in the global market;

- Security and Privacy: the Security and Privacy provided;

- Installation Cost: cost of the installation process.

In Table 1, we show a subset of the table only with the ILS mentioned by us.

Table 1 - ILS comparison [19]

	GPS	WiFi	QR Code	RFID (NFC)	Beacon (BLE)
Tracking Accuracy	Low	Low	High	High	High
Maintenance Effort	Difficult	Easy	Easy	Difficult	Easy
Industry Uptake	Low	High	Medium	Medium	High
Security and Privacy	High	Medium	Medium	High	High
Installation Cost	High	High	Low	Low	Medium

Analyzing the table above, GPS and WiFi technologies present low accuracy while the other three have high accuracy. So, between QR code, NFC and BLE technologies, although the BLE has more installation cost than the others, this one can be used and detected without the need of user actions and has an easy maintenance effort, this means, in the QR code technology, the end-user has to use his mobile device to read the QR code in order to access the information provided, and in the case of NFC, the maintenance effort is difficult, while the BLE technology, namely using beacons, provides the information of the device through the signal emitted, that can have a range of seventy meters and has an easy maintenance effort.

Taking this into consideration, we opted by the BLE technology and used Beacons to take advantage of this technology.

2.3. Building Information Modeling (BIM)

Building Information Modeling (BIM) is a collaborative process that consists of creating a 3D model of a building (see Figure 4), providing better building project

management since it includes information that allows "document management, coordination and simulation during the entire lifecycle of a project" [20].

This model provides detailed information about every building component *e.g.* the fire rating of a wall, or which spaces a door connects, but it is also possible to define additional information like how many chairs are in each room.
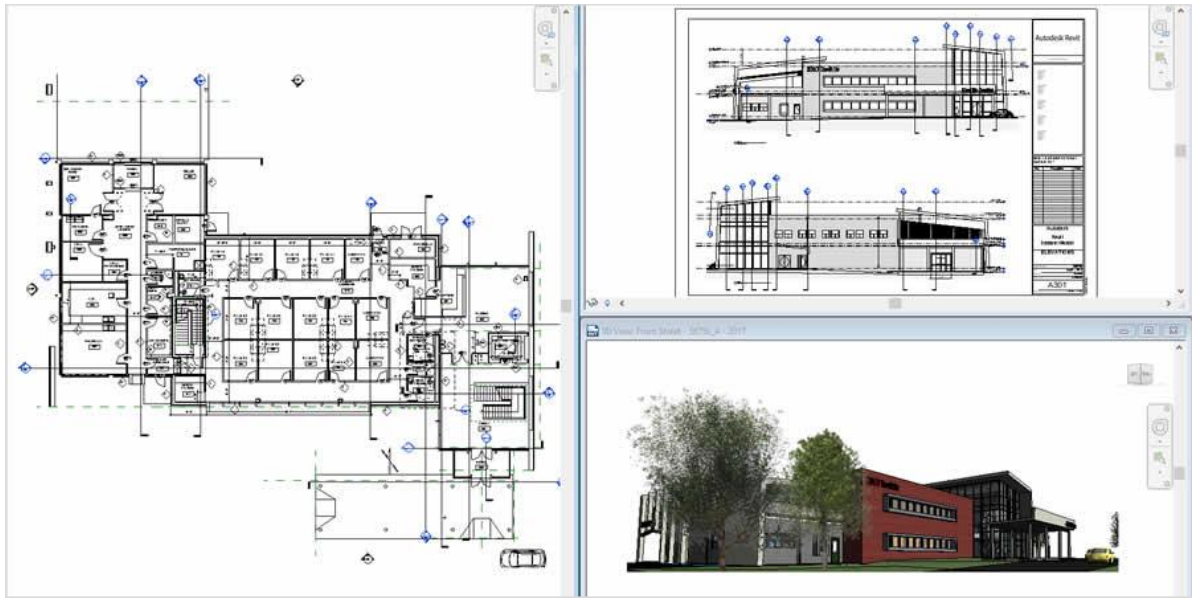
Figure 4 - Example of a BIM project [21].

Having a model with this detailed information and the possibility of extracting and updating it, brings the advantage of synchronizing to external tools or systems.

2.4. Database

In this dissertation, in order to store the Smart Places information that feeds the prototype, there is a need to have a database, so in this section, we present our research about the available databases, as well as, the advantages and disadvantages of each, finishing with some conclusions.

2.4.1. External and Local databases

Since one of our prototype components is a mobile application, we need to consider two types of databases in our research, namely, external and local databases.

External databases can be hosted on a dedicated server or can be cloud-hosted [22], but they have in common the need for internet access to establish a connection to them.

On the other hand, the local databases do not have the need for internet access, since it stores the data locally on the device, but if there is a need to store a huge amount of data, it has the disadvantage of overloading the device memory and may also have an impact on its performance.

Since we aim at providing information about an undefined number of Smart Places, the amount of data that needs to be stored can be huge and each mobile user may only need to access the information of a small number of Smart Places, so it would not be appropriate to store the information about all available Smart Places on their mobile devices.

With this, we decided to store the Smart Places information on an external cloud-hosted database that can be accessed from mobile devices.

2.4.2. Databases for Mobile Applications

As we already mentioned, the end-user of the developed prototype accesses the Smart Places information through a mobile application, so we researched available cloud-hosted databases that better suit mobile development.

During our research, we found several, like Couchbase Mobile [23], Azure Mobile Services [24], Cognito [25] and Firebase [26]. From there, we opted to use the Firebase that provides database and storage services and an API that allows the connection to multiple instances, this means, is possible to define to which database and storage we want to connect, that is something useful since this way is possible to have one Firebase instance for each Smart Place allowing to store their information on their own Firebase instance.

2.5. Content Management System (CMS)

In this section, we present the information obtained during our research for Content Management Systems, which helps in the task of data management by each Smart Place.

In our research, we focused on open-source CMS and found WordPress [27], Joomla [28] and Drupal [29]. These are three of the five most used Content Management Systems, according to a study carried out by *BuiltWith* in December 2016 [30].

Looking at these three CMS's, one thing in common is that all of them provide plugin developments based on the PHP language [31].

With this in mind, we decided to develop a PHP plugin that could be adapted to the different CMS's and used the Drupal as Content Management System for our prototype to develop, install and test the plugin.

2.6. Related Work

In the course of our research, we focused on approaches aimed at the guidance of users inside complex buildings especially shopping malls and museums, preferably those featuring BIM.

One approach we found where BIMs are used was [32], that uses a BIM tool to define emergency paths of buildings that can be extracted and then imported into a firefighter's guidance system. This system includes a mobile application in coordination with an ILS that combines the use of RFID, UWB and WLAN technologies to guarantee better performance in critical situations, like high humidity. This system is used in emergency situations where the intervention of firefighters is required, providing support to guide them through the emergency paths defined in the BIM tool. In addition, the system contains a back-office tool, where firefighters outside the building can also see the location of each one of the other firefighters inside the building in real-time (see Figure 5).
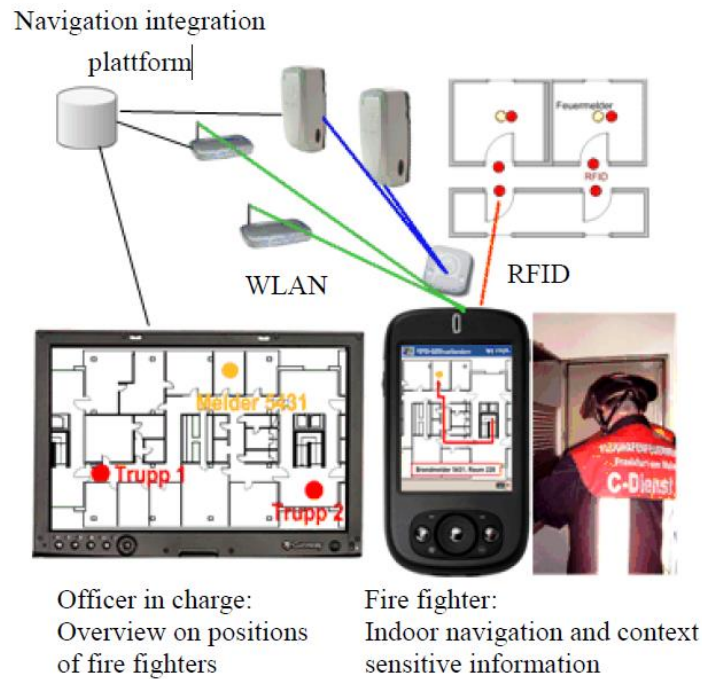
Figure 5 - System for emergency situations [32]

Another approach that we found in our research is [19] where the authors developed a system used to track and guide users within a university campus. To do that, the authors use BIM to define the position of each BLE device inside a building, as well as additional information like the closest stairs, the paths of the building, classrooms, etc. All this information is loaded into the system in order to be read by the algorithm and used in the mobile application. Initially, the users select the desired destination, taking into consideration the current location of the user, the mobile application presents the path, as well as some photos to help the user confirms that he is following the correct path (see Figure 6), that is updated while he is moving, based on the intercepted BLE signals.
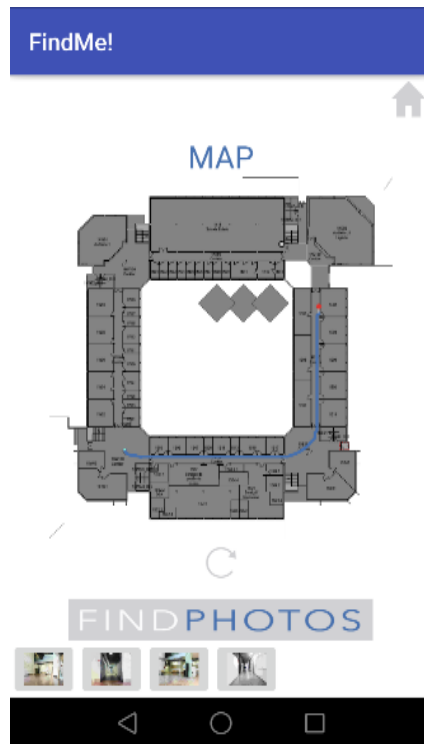
Figure 6 - FindMe! mobile application [19]

Also applied to a university campus we found [33] which, although it does not use BIM, uses BLE devices to check the position of people, that is used to provide relevant information about each place, *e.g* library, cafeteria or print shop, in opening days that can be very useful for the new users/students.

As we can see, BLE devices are very useful when we think of Smart Places being a crucial component of most systems. Another use case where this kind of device is used is presented in [34] where the authors use these devices to check when a person enters or exit specific places inside an office. In their case, this information helps in the office energy management, reducing the consumption of energy in a place without people. In [35] the goal is similar, but in this case is to make a better management of heating, ventilation and air conditioning in a building.

In addition to these, we found other works more focused on providing relevant information to building visitors. We found a study [36] of a system applied in a Zoo, that is aimed at providing guiding information. In this method, one mobile application was developed to provide information to the visitors taking into consideration the visitor location, so while the visitor is moving, the application intercepts the BLE signals and presents a notification. Each BLE device has an ID that matches an animal ID allowing

the mobile application to know the location of the visitor making it possible to show the desired information. Also, in the mobile application is possible to answer some questions about the animals, as depicted in Figure 7, to increase the interest of visitors. Furthermore, in this work was also developed a Content Management System to assist in the management of the contents that are provided to the visitors (see Figure 8).
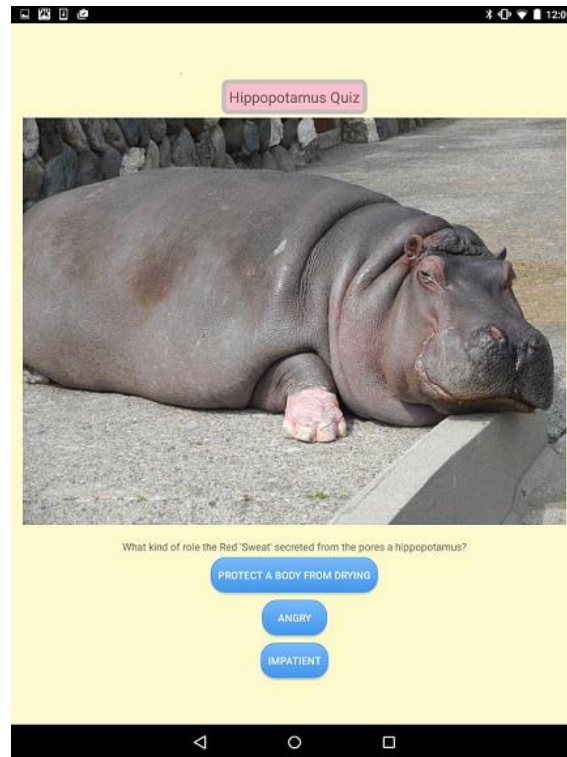
Figure 7 - Hippopotamus Quiz: Mobile Application [36]
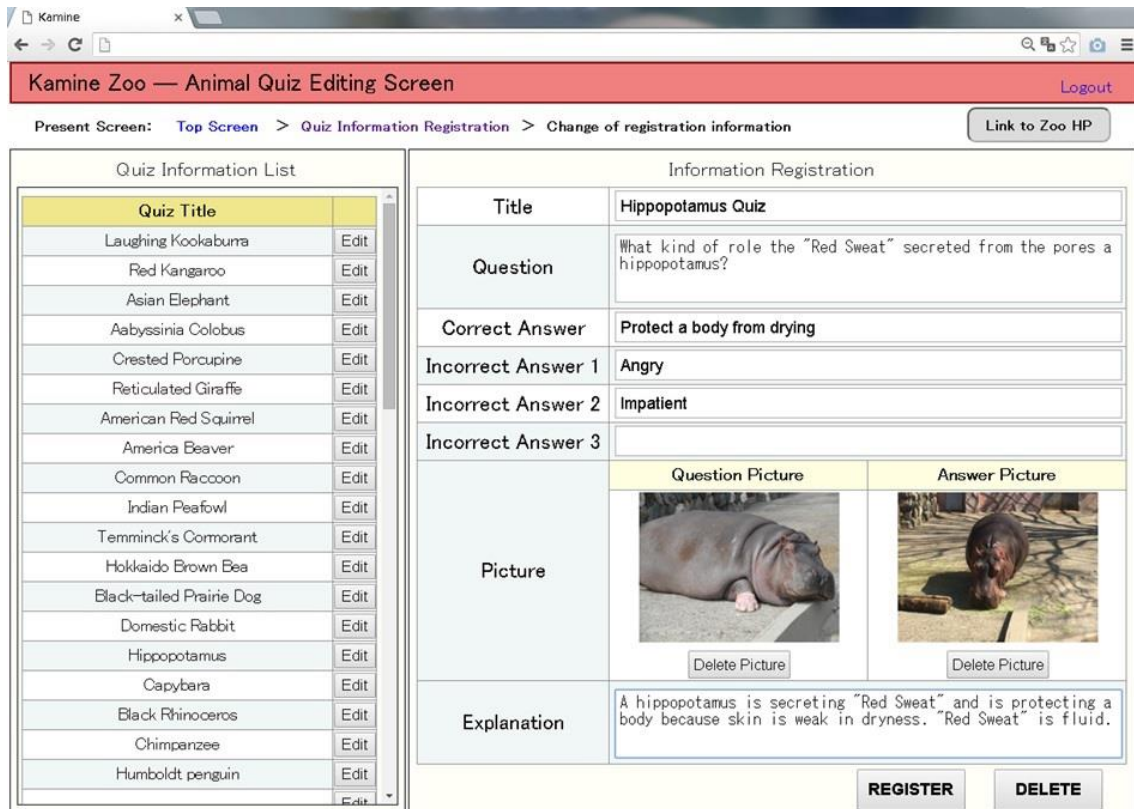
Figure 8 - Hippopotamus Quiz: Content Management System [36]

In [37], the authors also developed a guiding system but in this case for museums. In this system, the visitors install a mobile application and answer a couple of questions for profiling purposes that generate a QR code. When the visitor arrives at the museum, museum workers scan the QR code generated by the application and assign visitors a wearable device (see Figure 9), that must remain with the visitor throughout the visit. This wearable device, that includes a camera to monitor what the visitor is seeing and combine it with the location of the visitor, that is inferred through the sensing of BLE devices signals, the system identifies the piece of art being observed and the mobile application provides additional relevant information on that specific piece. This approach is expensive since the museums must guarantee the maintenance and availability of the wearable devices for each visitor, which is hardly practical and affordable.
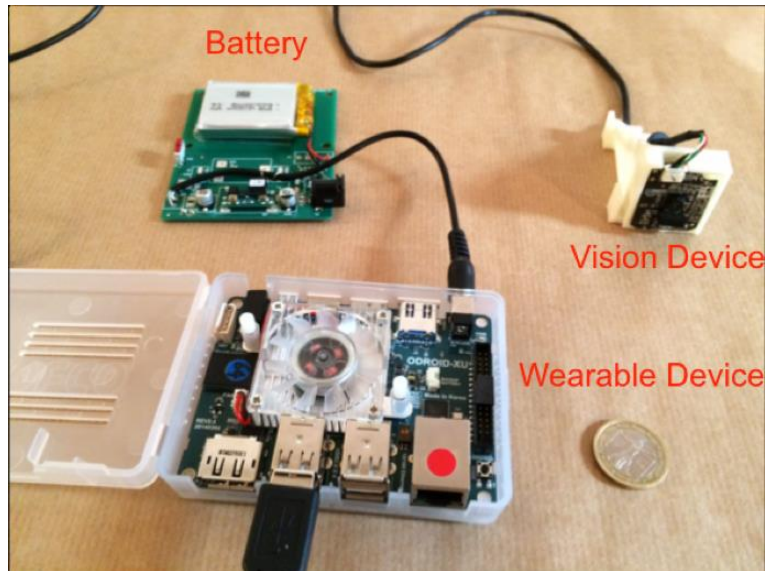
Figure 9 - Smart Museum: Wearable Device [37]

Another approach focused on enhancing museum visits is [38], where the authors propose the combined use of BLE devices, to create slave nodes, and Wi-Fi areas, to create server nodes. In this solution, the museum workers have a web-based tool to manage the information about each piece of art. When the visitor is at the museum, his position is inferred using BLE's signals and then is made a request to the server node, taking advantage of Wi-Fi areas data, to get the desired information (see Figure 10). Since this work was aimed at a museum from Italy, the system only provides information in Italian, which can be a disadvantage if we consider the tourist's needs.
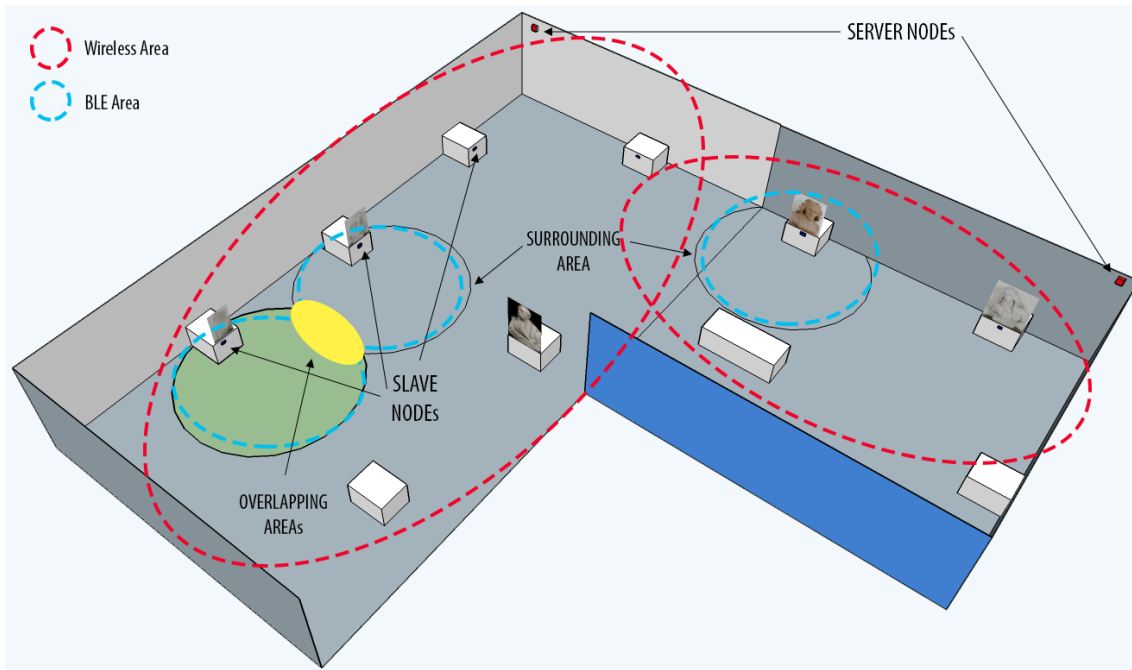
Figure 10 - Smart Museum: Wi-Fi and BLE areas [38]

In addition to these approaches, we also found proprietary products aimed at museums that seek to meet the needs mentioned above. The first is called izi.TRAVEL Help [39] and consists of a mobile application that provides information in different formats, such as audio, video and text, and a CMS to help museum curators manage the information provided to the visitors. This product, instead of using IoT devices as ILS to make visits more interactive, uses QR codes, making it necessary for the visitor to read the codes physically placed in the museum. The second product, called Locatify [40], is similar to the previous product but uses IoT devices to enhance the visiting experience, and the mobile application allows the user to choose between two languages, English and Icelandic.

As we mentioned in the previous chapter, we believe that it is more comfortable and preferable for the users to have information about several buildings or sites in just one application, hence we researched previous works aimed at satisfying this and found [41]. In this work, the authors proposed the development of a system aimed at combining information from a group of museums that belongs to the same district, namely Jongno district in South Korea, since the authors believe this approach could contribute to the attraction of more visitors to the museums.

2.7. Comparison and Conclusions

In this section we make a comparison between the related works mentioned, taking into consideration some factors that we define based on the facts mentioned in chapter 1.

So, the first is "Centralization", this means, the capacity to centralize information from several Smart Places in a single mobile application, as we consider that an important issue since it can bring more comfort and ease of use to the end-users.

The second one is "Multi-Language", meaning that the system allows the Smart Places to define and provide a set of languages that the end-users can choose, thus having access to the information translated into the desired language, without being limited to just one since a large part of the target audience is tourists.

Another factor that we consider as being important is the simplicity and cost of the system. So, the third factor is "Simple and Affordable" because if a system is complex and expensive to install and maintain, it leads to greater reluctance from building managers to accept it.

To guarantee that the system provides an interactive way to present the information to the end-users since we believe that is an important factor in the system usability, we defined a fourth comparison factor that is "Interactive". This factor refers to the capacity to provide relevant information taking into consideration the location within a building, *e.g* using IoT devices, interacting with the end-user without the need to perform any action, such as reading a QR code.

The last comparison factor that we defined is "BIM Integration" which is related to the capability to load data into the system extracted from BIM tools since we consider that it has a major impact on reducing the time spent defining the information for the system.

Table 2 shows a summary of the comparison between the products and approaches considering the factors referred above.

Table 2 - Comparison between the related works

	[32]	[19]	[33]	[36]	[37]	[38]	[39]	[40]	[41]
Centralization	-	-	-	-	-	-	-	-	✔
Multi-Language	-	-	-	-	-	-	✔	✔	?
Simple and Affordable	✔	✔	✔	✔	-	✔	✔	✔	?
Interactive	✔	✔	✔	✔	✔	✔	-	✔	?
BIM Integration	✔	✔	-	-	-	-	-	-	?

Looking at Table 2, it is possible to see that none of the mentioned related works meets all the factors, that we considered relevant based on the motivation defined in section 1.1, chapter 1, to provide a support system for complex buildings and a guide system for their users.

With this, we aimed at designing and developing a system that meets these five factors keeping it flexible so that it can be used in buildings with quite different realities and utilities.

3. Prototype Architecture

In this chapter, we present the architecture of our prototype while explaining each of their components and how each of them is connected. First, we explain the decisions made during the design of the databases and present their data models, as well as the reason why we did it in this way. Then we approach the Building Information Modeling followed by the Content Management System, explaining how they contribute to our prototype. To illustrate what the mobile users see while using our prototype, we show, in the Mobile Application subsection, the screens provided in the mobile application while explaining the decisions made. We finish this chapter with the BLE Devices section, where we expose how these devices are used and which are their impacts and importance on our prototype.

As we defined in section 1.2, chapter 1, the MOG architecture depicted in Figure 11 was designed and developed with the objective of providing smart and complex buildings managers of a fast and effective way to provide information to the building users while keeping it practical and comfortable to them by allowing access to information about several Smart Places without the need to install a specific application for each building or site.
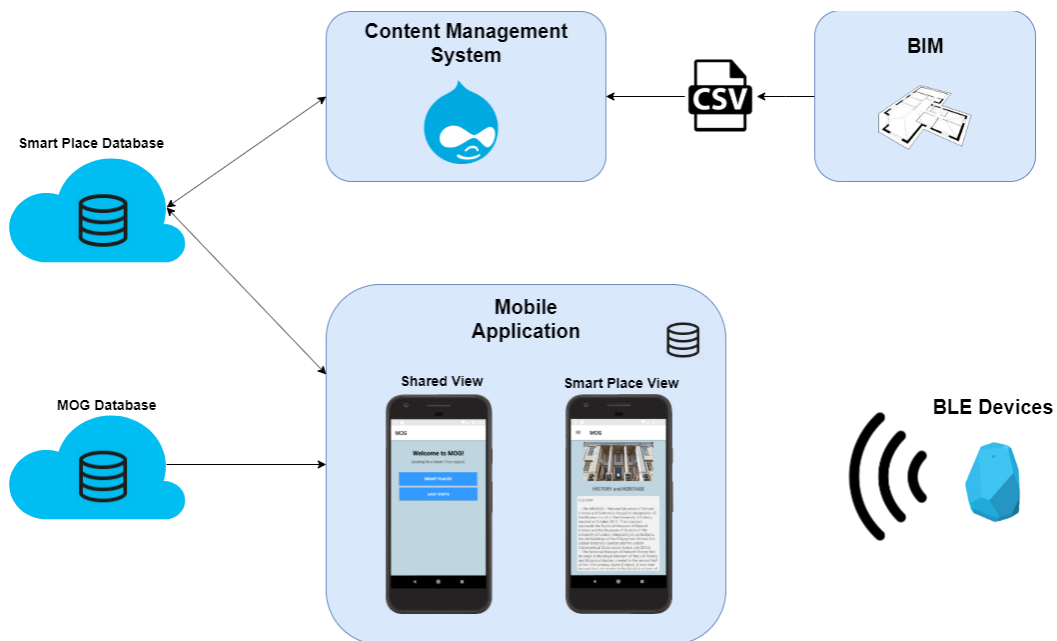

Figure 11 - MOG Architecture

In the design of our prototype, a particular feature is that it not only has a database, that is, for our prototype there is a database managed by those responsible for the prototype, that we named "MOG Database", where it stores general information about the Smart Places available and there is also a database for each Smart Place, named "Smart Place Database", so that it can have autonomy to access and manage its own data.

Since each Smart Place has its own independence to manage the data, for ease of use and to guarantee that the information stored in the database has the correct format and structure to feed the mobile application, we created a Content Management System, based on Drupal 8, to help the Smart Place managers in the data management task.

As we already mentioned, in order to reduce the time spent creating the information to be used in the prototype, we decided to provide a way to import data extracted from BIM tools into our prototype, through CSV files. So, to achieve that, the Content Management System is used as gateway between the BIM tools and our prototype.

The mobile application, as we represented in Figure 11, has two different views. The Shared View connects to the MOG Database, while the Smart Place View connects to the database of the corresponding Smart Place.

One of the factors that we defined as being important to have a good system is the "Interactive" factor. To achieve this, we opted to use combine the mobile application with IoT devices, specifically, BLE devices. This brings to the prototype a way to provide interactive information to the end-users.

In the next sections, we describe with more detail each component of this architecture.

3.1. Databases

In this prototype, we define one central database that is the MOG Database (MD) and another for each building or site featured, that we named Smart Place Database (SPD). This design was made in order to provide the Smart Place managers with total control over their database and of the contents that are shown to the visiting users. To facilitate the development of this prototype we opted for Firebase [26], namely the Firebase Realtime Database [42], that is a cloud-hosted NoSQL database [42], that also allows fast

development since it provides all the services that we needed and a simple way to connect to different databases.

The MOG database is intended to store general information about the Smart Places available in the system, as well as information necessary to establish an interactive connection with the database of each Smart Place as depicted in Figure 12.

```
{
  "smartPlaces" : {
    "smartPlace_1" : {
      "address" : string,
      "appInfo" : {
        "apiKey" : string,
        "applicationId" : string,
        "databaseURL" : string,
        "storageBucket" : string
      },
      "id" : string,
      "image" : string,
      "location" : string,
      "name" : string,
      "price" : string,
      "rating" : number,
      "schedule" : string
    },
    "smartPlace_2" : {
      .
      .
      .
    }
  }
}
```

Figure 12 - MOG Database (MD)

Although the Smart Place Database is managed by the managers of each Smart Place, thus giving them independence in the tasks of managing the content provided, it must be compliant with the defined data model that we explain next.

As we mentioned, we created three possible spaces in order to have a more flexible prototype which are the Interest Zones, Groups of Interest Points, and Interest Points, that follows the data model depicted in Figure 13.

```
"InterestZone": {                     "GroupInterestPoints": {              "InterestPoint": {
    "language_1": {                       "language_1": {                       "language_1": {
        "interestZone_1": {                   "groupInterestPoints_1": {            "interestPoint_1": {
            "calendar": string,                   "description": string,                "audioFile": string,
            "description": string,                "endDate": string,                    "description": string,
            "id": string,                         "id": string,                         "id": string,
            "imageFile": string,                  "interestPointsList": array,          "imageFile": string,
            "name": string,                       "name": string,                       "name": string
            "groupList": array                    "startDate": string               },
        },                                    },                                    "interestPoint_2": {
        "interestZone_2": {                   "groupInterestPoints_2": {                .
            .                                     .                                     .
            .                                     .                                     .
            .                                     .                                 }
        }                                     }                                 },
    },                                    },                                    "language_2": {
    "language_2": {                       "language_2": {                           .
        .                                     .                                     .
        .                                     .                                     .
        .                                     .                                 },
    },                                    },                                    .
    .                                     .                                     .
    .                                     .                                     .
    .                                     .                                 },
},                                    }
```

Figure 13 - Interest Zone, GroupInterestPoints and InterestPoint data model

These represent the most relevant information for users of the mobile application and can be displayed in a set of languages defined by each Smart Place in order to meet the specific needs of its visitors.

Each of these spaces must have information about its location within the building, to be possible to draw the already visited spaces on the application's Map screen, which means that those responsible for the Smart Place must fill in the MapInfo (see Figure 14) for each space, specifying the pixel coordinates and radius that is used to draw on the map. This information about the indoor location of each space can be imported into our prototype using the information extracted from the BIM tools.

```
"MapInfo": {
    "InterestPoint": {
        "interestPoint_1": {
            "radius": number,
            "xx": number,
            "yy": number
        },
        "interestPoint_2": {
            .
            .
            .
        },
        .
        .
        .
    },
    "InterestZone": {
        "interestZone_1": {
            "radius": number,
            "xx": number,
            "yy": number
        }
        .
        .
        .
    },
    "GroupInterestPoints": {
        "groupInterestPoints_1": {
            "radius": number,
            "xx": number,
            "yy": number
        },
        .
        .
        .
    }
},
```

Figure 14 - MapInfo data model

In addition to these objects, we also created the MainInfo object to store the information that is shown on the main screen of the application and the News object that has fields to store a title and a short description to show in the News List screen of the mobile application, but also a field named "description" to store the complete content of the news (see Figure 15).

```
"MainInfo": {                    "News": {
    "language_1": {                  "language_1": {
        "text": string,                  "newsList": [{
        "title": string                      "description": string,
    },                                        "shortDescription": string,
    "language_2": {                           "title": string
        .                                 },
        .                                 {
        .                                     .
    },                                        .
    .                                         .
    .                                     }]
    .                             },
},                                "language_2": {
                                      "newsList": [
                                          .
                                          .
                                          .
                                      ]
                                  },
                                  .
                                  .
                                  .
                              },
```

Figure 15 - MainInfo and News data model

Besides these objects, we have created others that serve to help and provide more control, to each Smart Place, of the contents presented in the mobile application.

So, to provide a way to the Smart Place to configure the translations of the sidebar menu that appears in the mobile application we created an object named Menu that has the fields depicted in Figure 16.

```
"Menu": {
    "language_1": {
        "classify": string,
        "communicate": string,
        "lastSpace": string,
        "home": string,
        "language": string,
        "map": string,
        "news": string,
        "report": string
    },
    "language_2": {
        .
        .
        .
    }
    .
    .
    .
},
```

Figure 16 - Menu data model

In order to each Smart Place define their own desired languages and provide the translations to their mobile users, we created two objects, the first is the Languages, where

the Smart Place defines the available languages, and the second is the SelectLanguageInfo, that is used to define the translation of the mobile application Language screen. In Figure 17 we present the data model for these objects.

```
"Languages": {                          "SelectLanguageInfo": {
    "language_1": [{                        "language_1": {
        "id": string,                           "confirmButton": string,
        "name": string                          "selectLanguageMsg": string
    },                                      },
    {                                       "language_2": {
        "id": string,                           .
        "name": string                          .
    }],                                         .
    "language_2": [                         },
        .                                   .
        .                                   .
        .                                   .
    ],                                  },
    .
    .
    .
},
```

Figure 17 - Languages and SelectLanguageInfo data model

The last object of our prototype is the Settings object (see Figure 18), that we use to store the names of the Smart Place general images, this means, the name of the Smart Place logo image, the map image, and the images to show in the slide presented in the Main screen.

```
"Settings": {
    "logoImageName": string,
    "mapImageName": string,
    "SlidingImages": array
},
```

Figure 18 - Settings data model

In section 3.4, we present more details about the interface of each object displayed to the mobile end-users.

3.2. Building Information Modeling (BIM)

In this section, we approach the BIM component of our prototype. As we already mentioned, the use of BIM is growing and can be a great help to the Smart Places in the data creation for our prototype. These BIM tools allow complementing the model with additional information about the building or spaces of the building, such as rooms, and any other information.

For our prototype, we decided to provide building managers with a way to upload information extracted from BIM tools. This results in a reduction of time spent creating information about each interest zone, group of points and point of interest, for the prototype since it is also necessary to define, for each of them, the location on the map so that mobile users can see it on the Map Screen of the mobile application.

Thus, using this model, it is possible to define the information of each prototype object, its building location, and also, to extract the building images, which can, in turn, be used in the mobile application on the Map screen.

In order to take advantage of BIM, the Smart Place managers can define in the BIM tool information about each space (InterestZone, GroupInterestPoints and InterestPoint). To do this is necessary to define the following information:

- spaceId – Identifier of the space.
- name – Name of the place that appear in the mobile application
- centerCoordinates – The coordinates allowing to draw in the map the visited spaces. This information must have the structure – (xx, yy, radius).
- datamodelObject – Identifies which object of the data model is. The allowed values are "interestZone", "interestGroup" and "interestPoint".
- childObjects – List of child objects taking into consideration the hierarchy defined in the data model.

The centerCoordinates and childObjects are not mandatory meaning that, if the coordinates are not filled, in the mobile application the user does not see that space draw on the map after he visit it, and if the childObjects field is not filled, the Smart Place managers can later add this information through the Content Management System.

Figure 19 shows an example of a CSV file with some information, well structured, that can be extracted from a BIM tool.

```
spaceId,name,centerCoordinates,datamodelObject,childObjects
dolphins,Dolphin Presentation,(231;307;127),interestZone,
mammals,Mammals,,interestGroup,[africanElephant,commonSeal]
africanElephant,African Elephant,(111;327;50),interestPoint,
commonSeal,Common Seal,(367;440;20),interestPoint,
```

Figure 19 - Example of extracted information from BIM

When finished, the managers can export the information from the BIM tool and import it to our prototype taking advantage of the Content Management System, which maps the information to the objects of our data model.

Besides this information, the BIM tool also allows extracting a 2D image of the building map that we is used to show on the Map screen of the Mobile Application, ensuring that when drawing each space, it is in the correct location of the image.

3.3. Content Management System (CMS)

As mentioned, one of the components of this prototype is the CMS, which was developed with the objective of providing the people in charge of the Smart Places a way to access and manipulate the data stored in their database.

The CMS ensures that all the data stored in the database have the correct format and structure to feed the mobile application.

In order to keep this prototype as open as possible, we chose to use the open-source Drupal 8 [29] CMS, since it is customizable and has a huge development and support community.

Thus, with Drupal 8 as our CMS, we developed a specific module that can be installed in any existing Drupal 8 site. This module creates a new menu tab on the site that allows staff to import the data exported from BIM, configure the available languages, general information of the Smart Place, the zones of interest, groups of interest points, each of the interest points and news relevant to the user.

For this type of Smart Places, one of the most important information is how users are interacting and it is here, in the CMS, that is possible to visualize some statistical information about this interaction, such as the number of users who have entered a zone of interest, the most visited zones and points of interest, the total number of users who have entered the Smart Place, and much other detailed information.

So, after installing our module in the Drupal 8 site, a new tab is available that after clicking on it, the site presents a page where several options are displayed. One of them is "Manage Application Content" that, once clicked, allows the user to select the object and language of the information he wants to see. Subsequently, it is displayed a list of

objects taking into consideration the selected options – Figure 20 shows a list of Interest Points with English as the selected language.

Figure 20 - Interest Points

For each object in the list, it is possible to click on "View", which opens a page with more details where the "Edit" and "Delete" options are available (as depicted in Figure 21).

Figure 21 - Details of Interest Point

3.4. Mobile Application

In this section, we explain the details related to the mobile application while we show the interface displayed to the end-users.

Through the mobile application, visitors access the relevant information provided by each Smart Place, so to ensure that users receive information based on their location within a Smart Place, they must give permission and allow access to Bluetooth and

Location information of the mobile device, allowing the mobile application to scan for the BLE devices signal. This enables the application to read the BLE signals and give access to the Smart Place information through mobile notifications.

As mentioned in the previous sections, we designed the system to allow a visitor to have access to information about a set of Smart Places in a single mobile application, so we split the application into two views, the Shared View, that shows the information managed in the MOG database, and the Smart Place View, that is managed by the Smart Place managers, which we explain next.

3.4.1. Shared View

The Shared View, connected to the MOG database, is displayed to users when they open the mobile application. The first screen presented to the user is the "Welcome Screen" (see Figure 22) with an option to see a list of available Smart Places and another to see his last visits.
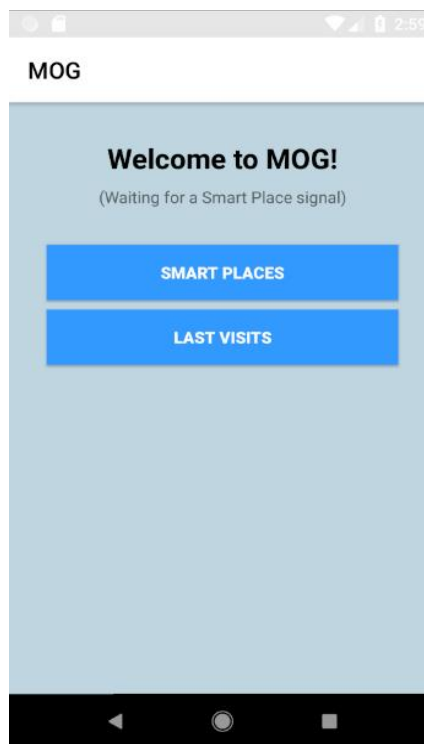

Figure 22 - Welcome Screen

The option "Smart Places" provides a list of available Smart Places in the system with their schedule and address, which uses the general information provided by the MOG database, which the user can use to plan their route (see Figure 23).
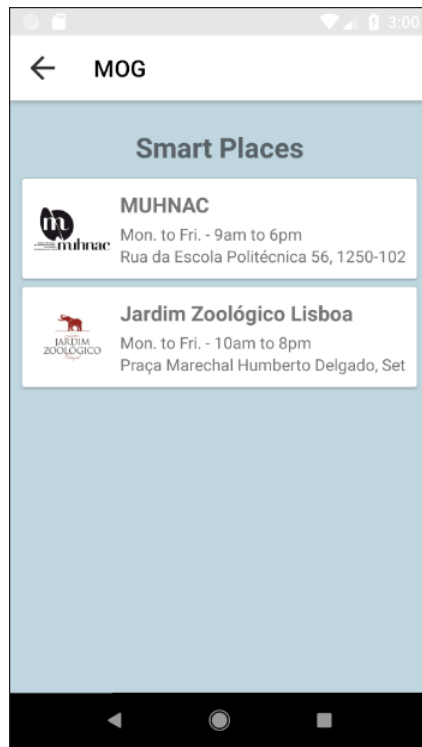
Figure 23 - List of Smart Places

In this list, after one of them is clicked, the mobile application shows more information about the place, namely the price, schedule, address, rating of the place based on the rates from other users and the rate that the user gave to that place.

Also, on this screen (see Figure 24) it is possible to click on "See Location" which redirects the user to Google Maps showing the address of the place. Another option is to click on "App" that opens the Smart Place View that we explain next.
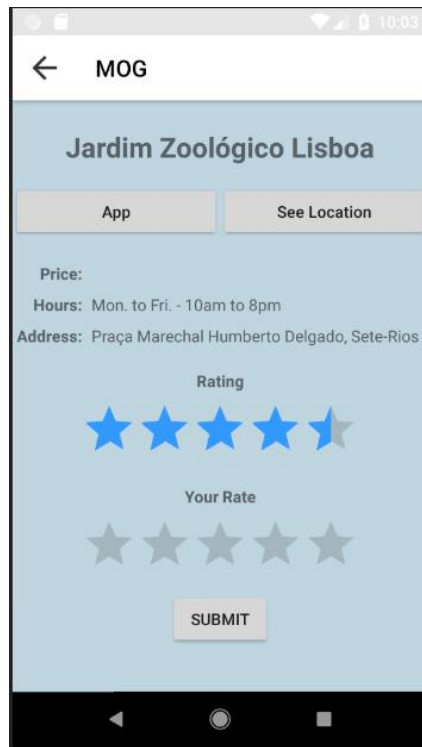
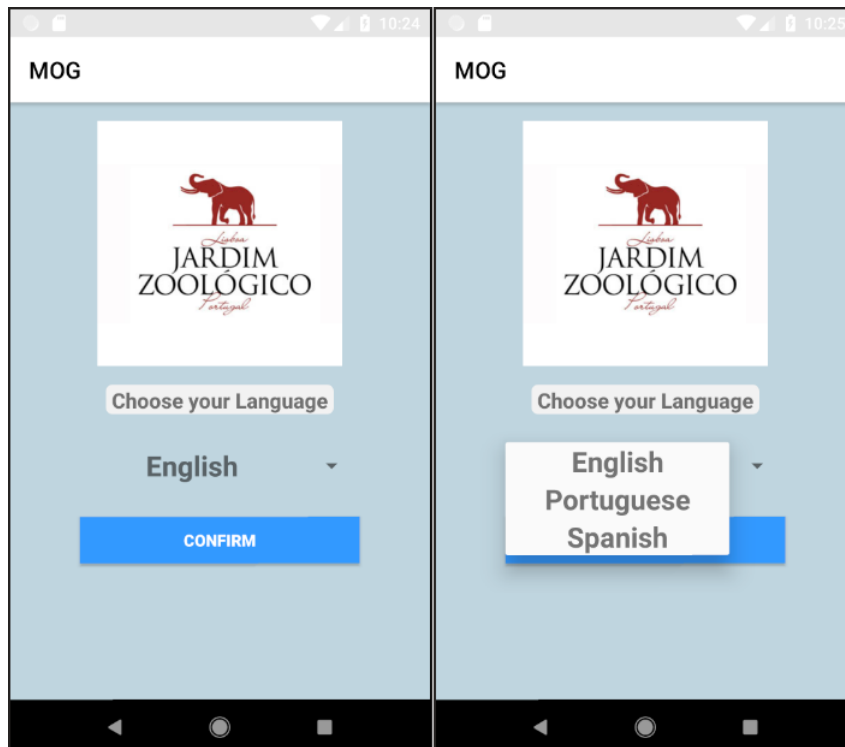**Figure 24 - Smart Place information**

3.4.2. Smart Place View

In the mobile application, when accesses this view is accessed, it connects to the database of the chosen Smart Place. At this point, the application provides access to the information provided by the Smart Place managers.

When this view is opened for the first time, for a specific Smart Place, the mobile application is redirected to a screen where it is possible to choose one of the languages available in that Smart Place as depicted in Figure 25.

Figure 25 - Language Selection Screen

After the language is defined, the application displays the main information of that Smart Place, which can be the history, some facts or any other information that was stored in the "MainInfo" object with an image slide, as shown in Figure 26.
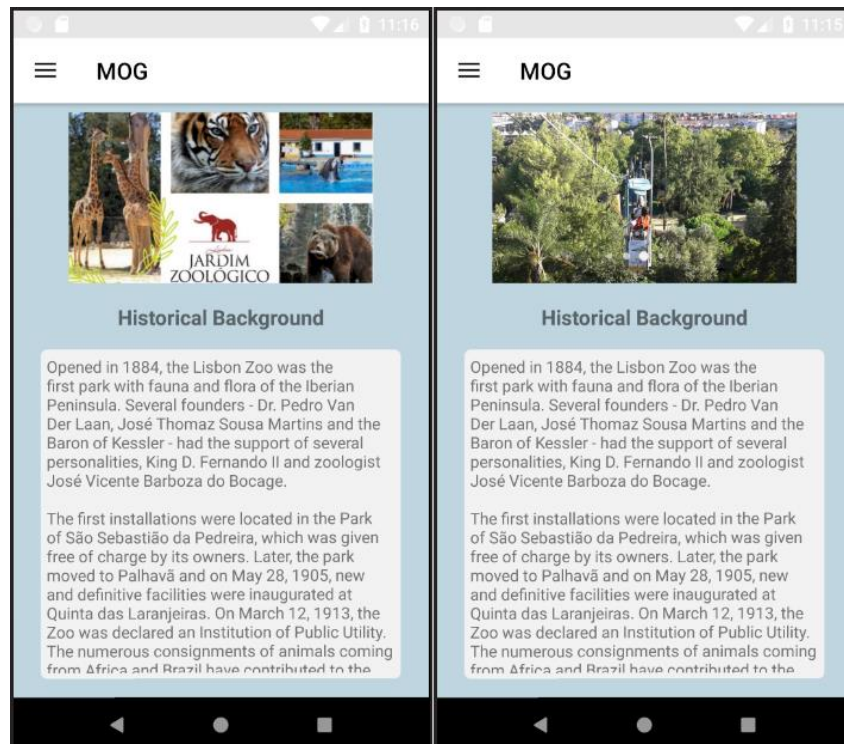
Figure 26 - Main Info Screen

In this view, we provided to the end-users a sidebar menu (see Figure 27) with the following options:

- Home – Opens the Main Info Screen;
- Map – Opens the Map Screen;
- Language – Opens the Language Screen;
- Last Space – Informs the user about the last visited space with the option to open the screen with information about that space;
- News – Opens the News Screen;
- Report an Error – Possibility to report an error;
- Classify this APP – Opens the Play Store.

Although the options have been named this way, each Smart Place can change their names as well as their translations.
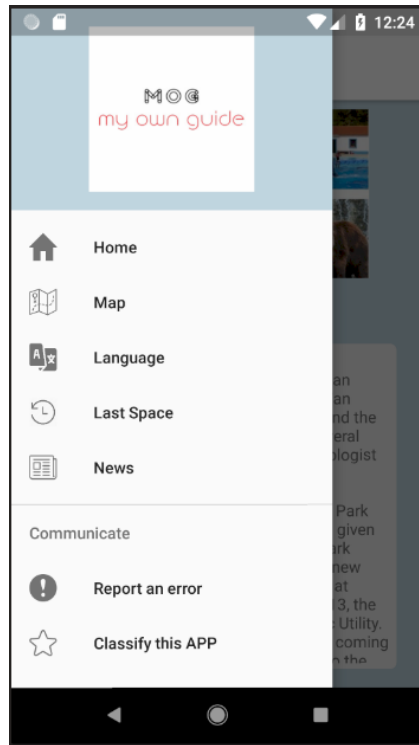
Figure 27 - Sidebar menu

Through this sidebar menu, is possible to access the Map Screen. There, is presented the Smart Place map, with the possibility of zooming and is also here that the spaces already visited are represented with a purple color (see Figure 28).


Figure 28 - Map Screen

Another option of the sidebar menu is to open the News Screen where all the news of that Smart Place are displayed as a list with a title and a short description, but when one of them is clicked, the mobile application displays a screen with the remaining information as depicted in Figure 29.
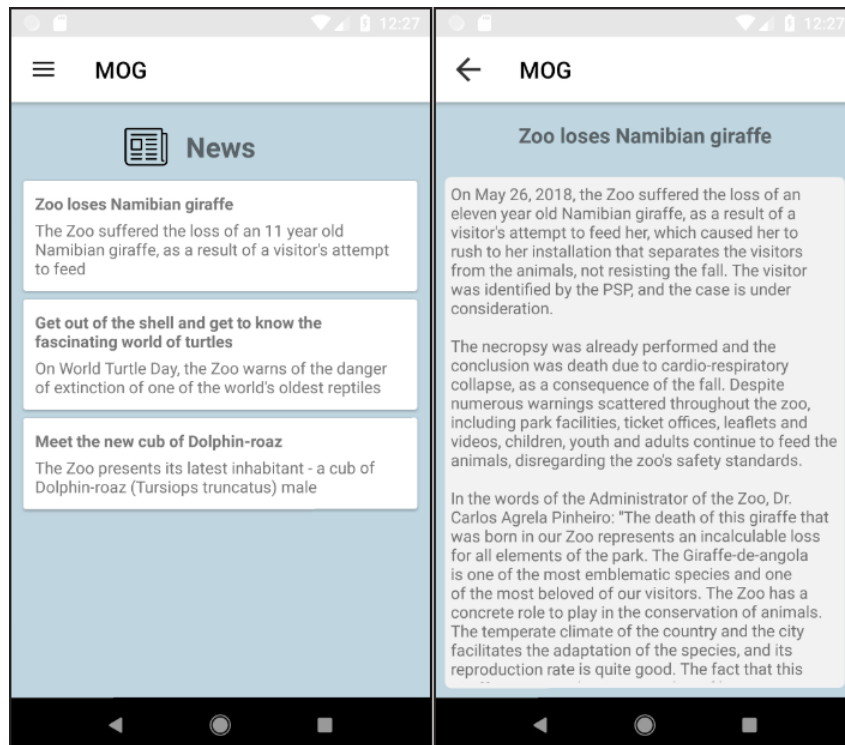
Figure 29 – News list and information screen

The option "Last Space" allows to have access to the information from the last space identified by the mobile application, this means, the space identified by the last BLE device signal that the application intercepted. After clicking this option, it is presented a popup informing which was the last space visited and asking if the user wants to see the space information and after the confirmation, the corresponding screen is opened.

The information of the interest points, group of interest points and interest zones, is only available when the mobile application intercepts a BLE signal. When this occurs, it is presented a notification that, after clicking on it, opens the mobile application on a screen showing the desired information (see Figure 30).
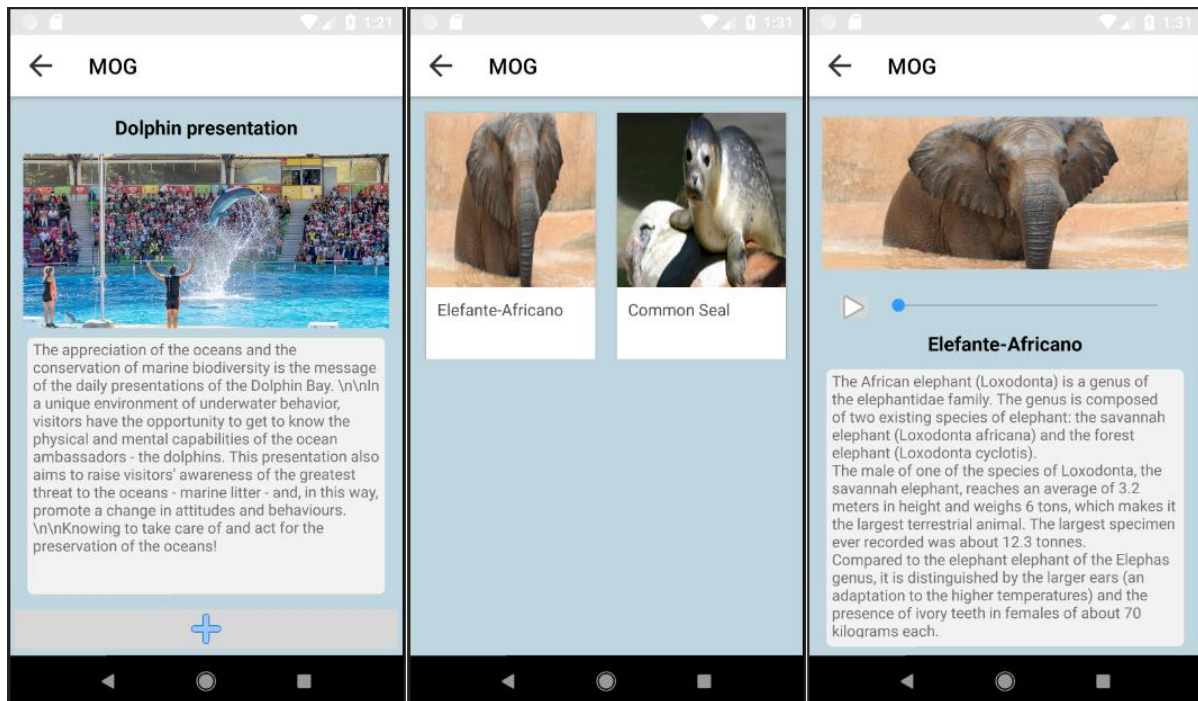
Figure 30 - Zone, Group and Interest Point screens

In the screen of an InterestZone, at the bottom, is a button with a '+' symbol, that when clicked, can have two different behaviors. The first is if the Smart Place defined that the InterestZone has more than one group of interest points and in this case, the user sees a screen with a list of the groups that are available. On the other hand, if the Smart Place defined that the interest zone only has one group of interest points the user sees the GroupInterestPoints screen, as the middle screen of Figure 30.

In the screen of an InterestPoint, as the right screen of Figure 30, we show a progress bar and a button to control the audio provided by the Smart Place, but if the Smart Place does not want to provide an audio file for a specific InterestPoint, in the screen that button and bar does not appear, and the screen contents adapt to it.

3.5. BLE Devices

In this section, we approach the BLE devices component. As already mentioned, these devices [14] allow users to receive notifications and be redirected in the mobile application to the screen with relevant information considering their location. This allows the creation of a more interactive and immersive environment that enhance the visiting experience for the user.

The BLE devices used in this work were beacons from Estimote [18] and we took advantage of their Proximity SDK [17]. This SDK allows defining multiple attachments to the beacon, which are key-value pairs, allowing us to get the values in the mobile application when an event is triggered.

There are three types of events that can be monitored, which are the "onEnter", "onExit" and "onChange" [43]. The "onEnter" is triggered when a user enters the range of a beacon, the "onExit" is when a user leaves the range of a beacon and the "onChange" is when a user remains within a range of a beacon or multiple beacons, but he moves, entering or exiting the range of a beacon, this means, when the number of beacons intercepted change.

So, although these three types of events allow great flexibility to define different behaviors for only one beacon, as we want to keep the system simple taking into consideration that it can be used in Smart Places with completely different needs and realities, we chose to use only the "onEnter" event.

As we previously mentioned, in order to have a flexible system we have created three possible spaces that are the Interest Zone, Group of Interest Points and Interest Point, so each BLE device need to have as attachments the identifier of our prototype, a Smart Place identifier and the space identifier that are sent through Bluetooth signals. If the beacon has more than one space identifier, the mobile application considers the most detailed, this means if the beacon has an identifier to an InterestZone and another to an InterestPoint, when the user enters in the beacon range, receives a notification informing about the InterestPoint. One example of beacon attachments configuration is depicted in Figure 31 where we defined all the acceptable keys, but in order to work as expected, it is only necessary to define the "beacon_to", "smartPlace_id" and just one of the spaces identifier.

Key	Value	
beacon_to	MyOwnGuide	Remove
smartPlace_id	lisbon_zoo	Remove
interestZone_id		Remove
groupInterestPoints_id		Remove
interestPoint_id	elefante_africano	Remove

➕ Add Attachment

Figure 31 - Beacon attachments configuration

When a mobile application user enters a beacon range, the mobile application accesses the MOG database to obtain the information needed to connect to the corresponding Smart Place database. After that, this information is used to connect and gather information about the space identified by that BLE device in order to display the relevant information to the user.

Although, in order to guarantee that the user does not receive multiple notifications consecutively about the same space, the user only receives a notification when he enters a beacon range and that beacon identifies a space different from the previous one, this means, if a user enters in a beacon range and the beacon identifies the InterestPoint X, and then he enters the range of a beacon that identifies the same InterestPoint he won't receive a notification. If for some reason the user wants to see the information about the last space, he can use the option "Last Space" of the sidebar menu on the mobile application.

We opted for this approach since it can bring more flexibility to the system, which means, the location of each BLE device within a Smart Place and the signal range defines the areas where users intercepts it, resulting in a notification on the mobile device. So, the location and range do not mean or represent that the identified space is at that location, but it can mean that the user is about to enter that space, or he is passing near, and the Smart Place managers want to inform the user about that.

With this approach, if a Smart Place has a big room with four entries that represents just one InterestZone, instead of configuring one beacon with a huge signal range, that

may have negative impacts on the beacon battery life, the Smart Place can put four beacons, one in each entry, with a small range identifying the same space. Since our prototype does not generate a notification when the "onEnter" event is triggered from a beacon that identifies the same space, it ensures that the user receives a notification when entering the room, but not when leaving.

4. Prototype Applicability

In this chapter, we demonstrate how this prototype is flexible and can be applied to different types of infrastructures while providing relevant statistical information about people's inflows, besides being useful and comfortable to the end-user by having information about several smart places in a single application.

Since we did not have the opportunity to deploy our prototype in a real environment, we decided to proceed with a validation per case study, so we created two examples of Smart Places with different building types and needs. The first example is applied to a museum (Smart Museum) and the other to a shopping mall (Smart Mall), and for each, we configured some beacons to represent different spaces, based on their maps, as well as their information to be shown in the mobile application.

4.1. Smart Museum

Our prototype, when applied to a museum, can be an advantage as it allows museum managers to provide relevant information taking into consideration the location of the visitor, e.g. when a visitor enters an exhibition. Also, there is a greater likelihood that linguistic needs are met as the prototype allows the museum to define multiple languages and their translations, thus allowing the information to be presented more clearly to the end-user.

As an example of a Smart Museum, we used the MUHNAC that is a National Museum of Natural History and Science, located in Lisbon, Portugal. The information used is public and can be found on the museum's website [44].

Although we use real information available on the website, the information of each museum collection, exhibition or item may not be present at the museum location we mentioned.

4.1.1. BLE devices

In this subsection, we propose the location and configuration of the BLE devices taking into consideration the information provided on the MUHNAC website and considering only the floor 0.

Figure 32 shows a map of the floor 0 with five rooms identified from A to E.
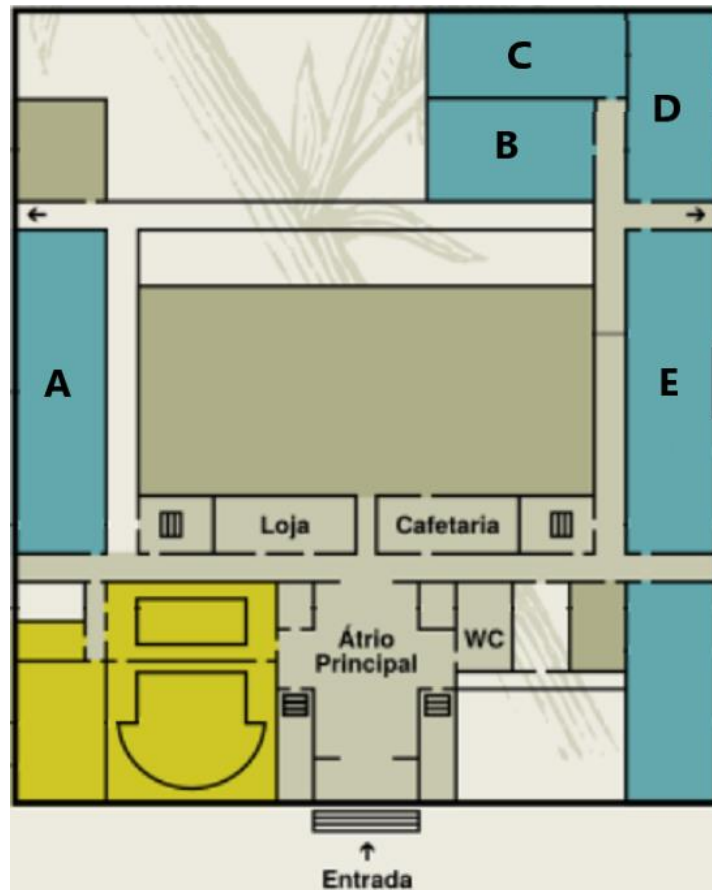
Figure 32 – Floor 0 of MUHNAC museum

One important step to define where to put the BLE devices, besides taking into consideration the budget in order to understand how many of them can be used, is to understand how the Smart Place wants to show the information to the users.

Since this is just a proposal, we just considered the type and distribution of interest points in each room, not taking into consideration the budget.

The room A has four big art pieces, so in this case our suggestion is to have one beacon (beacon nr. 1) at the door with a short range that notifies the users when they pass at the door, that identifies a Interest Zone, to make an introduction about that room, and another four beacons representing each art piece, identifying Interest Points.

Inside room B, there are several pieces of art grouped into 4 distinct groups. So, since it would be very expensive to have a beacon for each piece of art and it would be complex to ensure that the signal of each is correctly restricted to identify only the corresponding

piece of art, our suggestion is to have one beacon at the door and four beacons, each identifying one group of art pieces. To do this is necessary to have four GroupInterestPoints objects, each with a list of interest points that belong to that group.

Since room C only has one big art piece, we suggest having just one beacon, identifying an InterestPoint, placed at the entrance so that the visitor receives a notification upon entering the room.

In room D, the museum has several art pieces, just like room B, but in this case, they are not grouped. So, besides having a beacon at the entrance, we would suggest having another beacon in the room that identifies a GroupInterestPoints meaning that the user, at the mobile application, sees an interface showing a list of art pieces.

The last one, room E, has two entrances and several art pieces split into three groups. In this case, we suggest having one beacon in each entrance, and three beacons representing each group of art pieces.

In Figure 33, we show a visual representation of the beacon, numbered from 1 to 18, placed in each room.
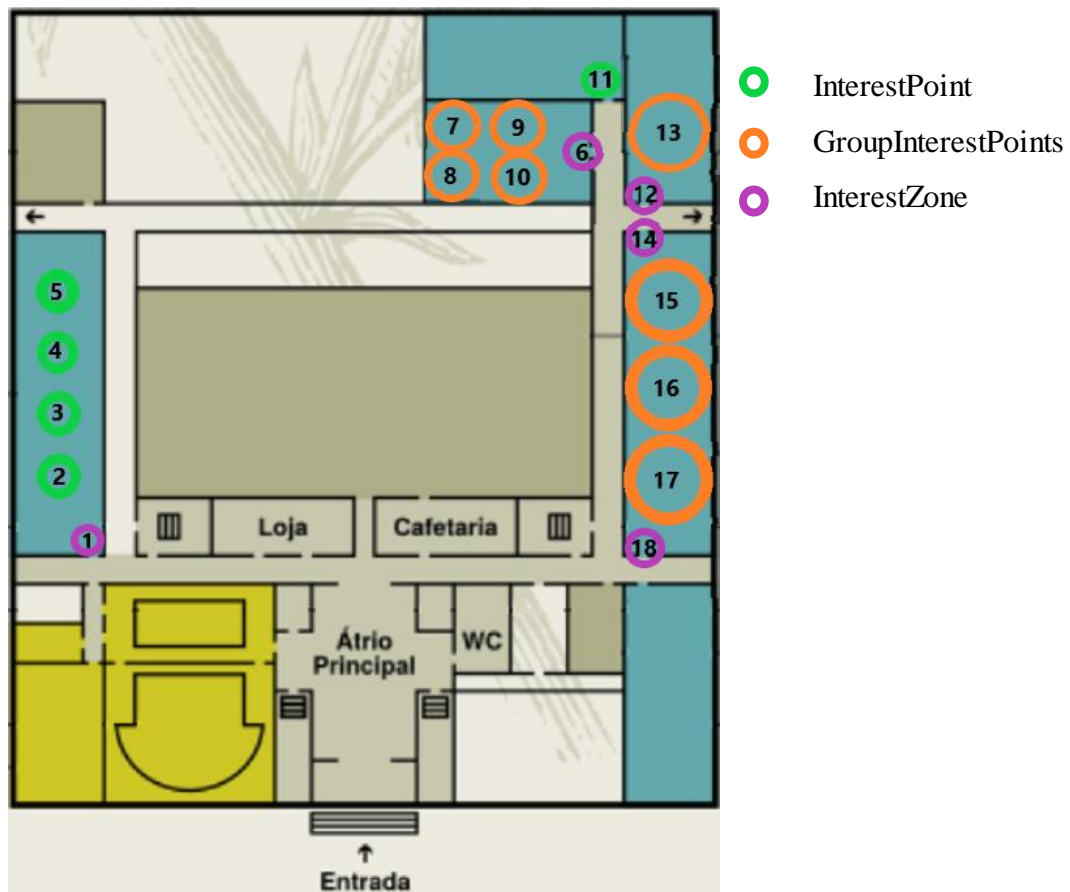
Figure 33 - BLE devices location at MUHNAC

4.1.2. Mobile Application

In this subsection, we explain how each space is presented in the mobile application to the end-users.

As proposed, rooms A, B, D and E have a beacon at their entrances that represents an InterestZone. As an example of an InterestZone, we use information about the exhibition "HANDS-ON" of the MUHNAC museum.

So, whenever a user enters one of these rooms, they receive a notification (see Figure 34) on their mobile device informing that they are in a zone of interest and, by clicking on the notification, they see the information as shown in Figure 35.

Figure 34 - Notification of HANDS-ON exhibition
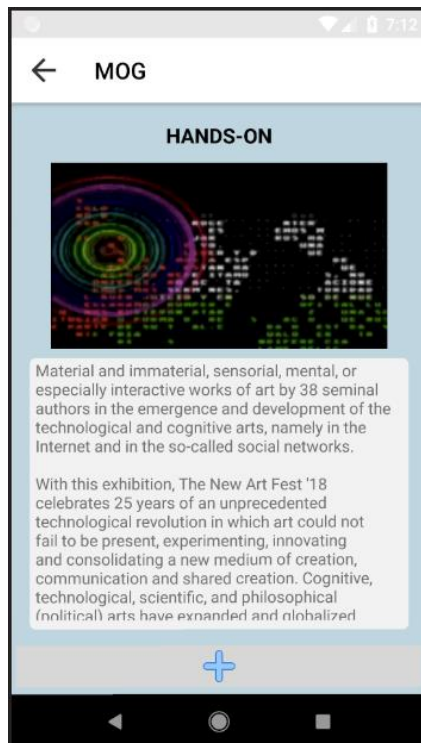
Figure 35 - HANDS-ON as InterestZone

In addition to the InterestZone, users can also receive notifications about GroupInterestPoints, which can be found in rooms B, D and E using our proposal. In this case, in addition to receiving a notification upon entering the area covered by each beacon

signal, users also receive a list of interest points that are present in the GroupInterestPoints (we use the Birds collection of MUHNAC as an example). To do this, in the mobile application, it is shown the list of interest points as depicted in Figure 36.

Figure 36 – Birds collection as GroupInterestPoints

At this moment the user has access to the information of all the points of interest present in this group and can click on one of them to access his information.

In addition to being able to access the information of an interest point through the screen of a group, the user can also access the information whenever he intercepts the signal of a beacon that represents an InterestPoint. In both cases, the information are shown as depicted in Figure 37, where we used information about "Martim-Angler-Great".

Figure 37 - Martim-Angler-Great as InterestPoint

4.1.3. Benefits

In this subsection, we present some benefits of our prototype when used in a museum.

To the museum visitors, our prototype provides access to the museum information, in several languages, that can be not available physically at the museum, but also can be used as a guide taking into consideration that most museum guides present information in two or three languages.

Besides that, the museum visitors also have a visual representation of each space that he has already visited, on the museum map.

From the Smart Museum perspective, they have a simple and affordable system that can be used to guide their visitors and can also complement, or even help, the people who are guiding the visitors.

Since with our prototype is possible to know that a visitor entered/visited a specific space, and this information is stored in the Smart Place Database, the museum has access to relevant data about the interactions of their visitors within the Smart Place, such as the

number of visitors per each exhibition, the total number of visitors in a specific date interval, among others.

4.2. Smart Mall

As we already mentioned, our prototype can bring benefits to Shopping Malls, since it can be used, besides providing guidance, for advertising purposes.

As an example, in this section, we used information from Surrey Quays shopping, as it presents on its website [45] several relevant information, such as a shopping map, to use as an example in our prototype.

As for the Smart Museum example, in this section, we propose the location of the BLE devices, as well as the type of space they identify. Below we present examples of how it is presented in the mobile application and finish with the benefits of this prototype when applied to a Smart Mall.

4.2.1. BLE devices

In this scenario, our suggestion is to place BLE devices at the entrances of each store, identifying an InterestZone or an InterestPoint, depending on the information that each store wants to provide to its customers.

To apply the example of our prototype, we focus on the right side of level 0 of the map in Figure 38.

Figure 38 - Surrey Quays Map

We use as an example, four stores, namely "Starbucks" and "Poundland" as interest points and "Boots" and "Yours" as interest zones (see Figure 39). Since "Boots" is a big store we simulate that has two entrances or one big entrance, and in this case is better to place two beacons in order to define a range that can cover the entrances. If we place just one beacon, this would cause the beacon's signal to have to be larger, allowing the signal to be captured at a greater distance from the store entrance, both in the hallway and inside the store, as the example of Poundland store, something that might not be the desired. This definition is subjective since, as already mentioned, it depends on how each store wants to present the information.

**Figure 39 - Surrey Quays Level 0 (right side)**

Taking into consideration our data model, the BLE devices identifying InterestZones can have a group of interest points associated, allowing the store to define for example a list of specific products that want to promote. On the other hand, the BLE devices identifying interest points can be used to generally promote the store. Both examples are detailed in the next subsection.

4.2.2. Mobile Application

In this subsection, we show how the information about the Smart Mall is presented to the mobile application users.

As we explained in the Data Model section, we have the object "MainInfo" that is used to store the information that is displayed to the user when he enters in the Smart Place View. In the scenario of a Smart Mall, we used this object to store the "About us" information (see Figure 40).
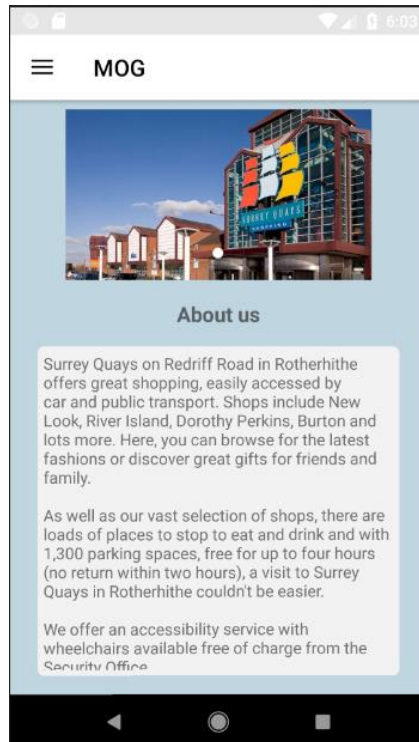
Figure 40 - 'About us' as MainInfo

A Shopping Mall is a place that can have some activities or events to attract more people, so to provide this kind of information, when using our prototype, the News object can be used. In the Surrey Quays website [45], we found some information that can be used as an example, namely, the "Little Explorers at Surrey Quays" and "JD Sports | Back to School" events.

After storing this information in the News object, the mobile application user when opens the News screen, sees the list of news as depicted in Figure 41.
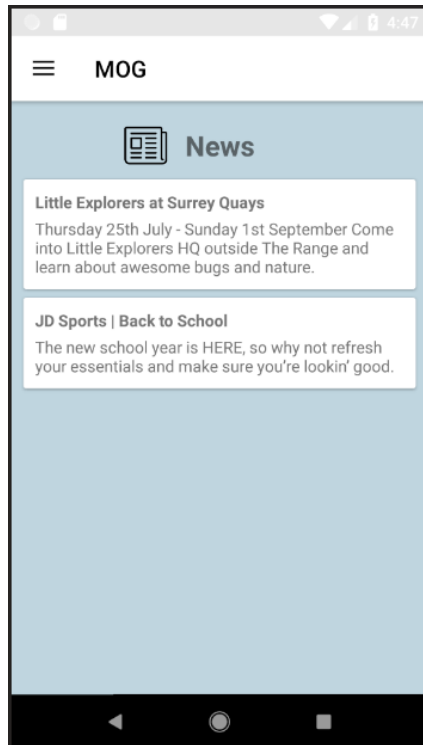
Figure 41 - News List

Then, if he desires to see more details about one of the news, he can click on the desired one and sees the information as shown in Figure 42, where we used the information of "JD Sports | Back to School".
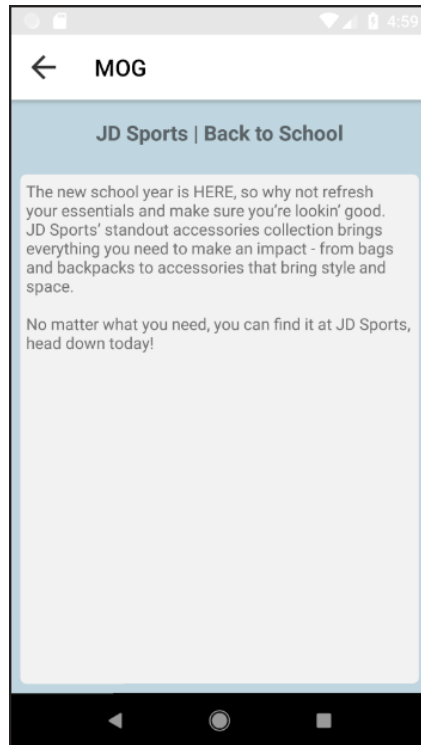
Figure 42 - JD Sports | Back to School

When the visitors are walking through the hallways, if they intercept a BLE device signal, they receive a notification based on what the BLE device is identifying, so taking in consideration our example of where the BLE devices are placed, if a visitor intercepts the signal of the BLE device identifying the Starbucks store, after clicking on the notification the user sees the information as depicted in Figure 43.
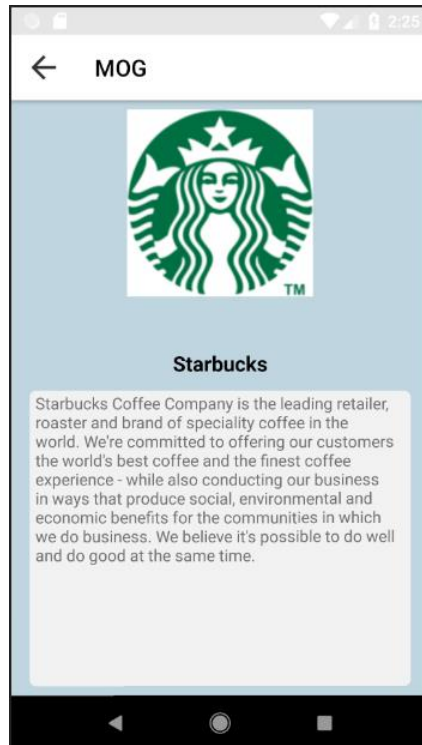
Figure 43 - Starbucks as an InterestPoint

Besides the *Starbucks* store, we also defined the *Poundland* as an InterestPoint, so it has the same behavior and layout.

On the other hand, we defined the *Boots* and *Yours* stores as InterestZone, and since both have the same layout, we only represent the example of *Yours* store.

After a visitor intercepts the BLE signal and clicks on the notification, he sees the information as shown in Figure 44.
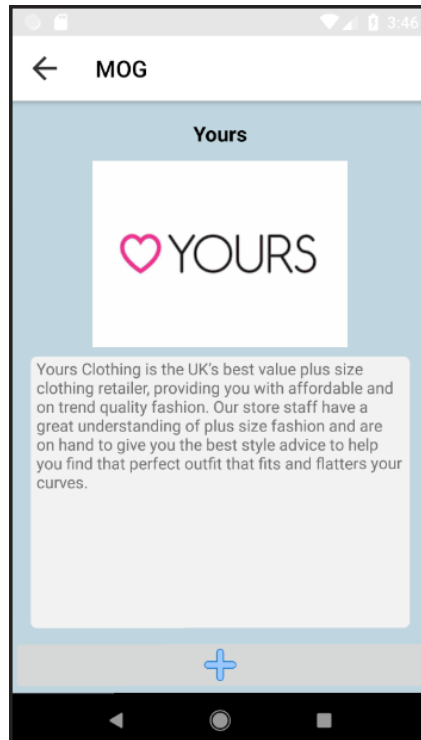
Figure 44 - Yours store as InterestZone

On this screen, the visitor can see a general description of the store but also he can access information about specific products that can be defined by the store. For this example, we defined just one GroupInterestPoints for this InterestZone, meaning that, if the user clicks on the "+" button, he accesses the screen shown in Figure 45.
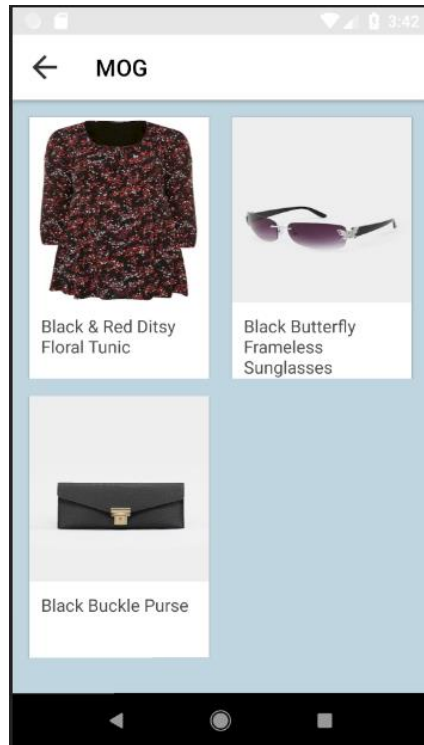
Figure 45 - Yours products grouped as GroupInterestPoints

This list of products can be products that are on promotion, *e.g*, the second product of the list, "Black Butterfly Frameless Sunglasses" are 20% off, so when the user clicks in that product the mobile application opens the screen corresponding to an InterestPoint with the information defined for this product (see Figure 46).
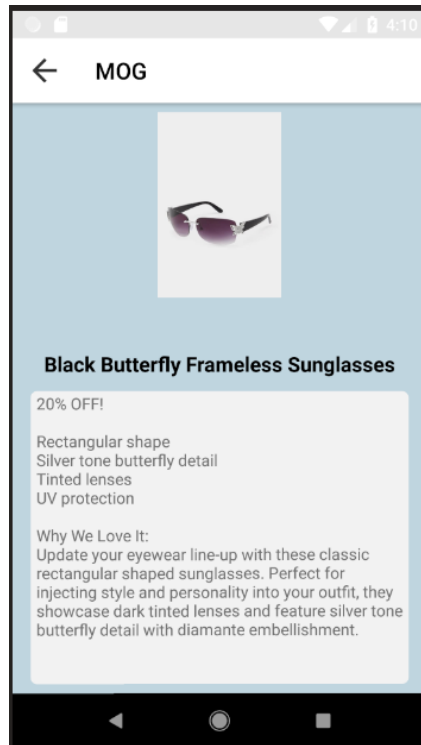
Figure 46 - Sunglasses from Yours store as InterestPoint

4.2.3. Benefits

In this subsection, we present some benefits that our prototype provides when used in a Shopping Mall.

As we already mentioned, our prototype provides to the end-users relevant information taking into consideration his location, so, when used in a Shopping Mall, it can be used to inform the user about special offers, products that are on promotion or even new products available at the store when he is passing next to it.

For the Shopping Mall, it can be used to provide a simple system that allows each store to promote themselves and their products while keeping it affordable for the mall, but also, it can be used to promote events that will happen in the mall, like in festive seasons.

Furthermore, as the mall has access to statistical data about the inflows of people to each space, they can use it to identify less affluent spaces so that, for example, the advertising of these spaces can be improved.

4.3. System Comparison

In this section, we make a discussion and comparison between our approach and the ones mentioned in the section 2.6, chapter 2.

As mentioned, we have found some approaches with the aim of responding to the needs of complex buildings, namely those related to guidance and contextualized information for their users/visitors.

First, we mentioned two solutions that are aimed at guide users inside a building taking into consideration the paths and information defined in BIM. The [32], uses BIM to define emergency paths of a building and then can be imported to a system, feeding a mobile application that can be used by firefighters in rescue missions. Also, the authors of [19], proposed and developed a similar system but applied it to a university campus. This work is aimed at providing assistance to students of a university to find the desired place. These approaches are not aimed at enhancing the visiting experience of building visitors or users, but the result is similar, this means, the resulting system has a mobile application that can guide users, based on BLE devices signal and taking into consideration the information defined in a BIM tool.

Also applied to a university campus, we found the [33] but in this case, the authors do not take advantage of the BIM capabilities, but as our prototype, the aim is to provide information about each place of the building.

In our research, and since BLE devices are an important part of almost Smart Places, we also found works that take advantage of BLE devices, such as [34] and [35], but are aimed at providing information that can be used to have better management of energy consumption taking into consideration the number of persons in each building place.

Then we approached works that are aimed at enhancing the visiting experience, and we mentioned the [36], that is applied at a Zoo and the [37] and [38] that are focused on the visiting experience of museum visitors.

In [36], the authors propose a system where each beacon has an id that corresponds to an animal at the Zoo, used then to get the relevant information in order to provide it to the user, but is limited to one language.

Making a comparison with the approach in [37], their approach brings some functionalities that our approach does not, such as communication to social networks, in this case, Facebook, but also brings a profiling feature that in our understanding is very interesting and can bring benefits to its users, such as, providing relevant information based on their profile. However, this solution is complex and can be too expensive, while our system was designed and developed aimed at being affordable and simple.

On the other hand, the approach proposed in [38] it's simpler but has the disadvantage of providing information only in Italian, that if we think of buildings, in this case, museums with foreign visitors, is a big disadvantage, while our prototype brings to the visitor a way to choose from a set of languages defined by each place.

One of the differentiators of our prototype is the centralization of information from different Smart Places, which can be sites, buildings or any other controlled space. We think this brings benefits to the final users since they can plan and make the most of their visits without the need to install several applications. This idea of centralization was already mentioned in [41] and the authors proposed the development of a centralized system limited to a geographical area, which was not developed, and hence we cannot make a comparison between the technologies.

We also analyzed some products and the first product mentioned was *izi.TRAVEL* but we consider a disadvantage the fact that does not use IoT devices to turn the visits more interactive. Another product is the *Locatify* that uses BLE devices but like the other products and technologies, it is one application per each museum, bringing to the visitors the need to download one application per Museum that wants to visit.

Table 3 shows a summary of the comparison between the products and approaches considering the following factors:

Table 3 - Comparison between the related works and our prototype

	MOG	[32]	[19]	[33]	[36]	[37]	[38]	[39]	[40]	[41]
Centralization	✔	-	-	-	-	-	-	-	-	✔
Multi-Language	✔	-	-	-	-	-	-	✔	✔	?
Simple and Affordable	✔	✔	✔	✔	✔	-	✔	✔	✔	?
ILS	✔	✔	✔	✔	✔	✔	✔	-	✔	?
BIM	✔	✔	✔	-	-	-	-	-	-	?

5. Conclusions

In this work, we designed and developed a prototype whose main objective is to provide big and complex building managers a system, aimed at enhancing the visiting experience by providing relevant and interactive information based on the user location, that can be easily deployed and maintained while keeping it affordable. Also, the prototype was designed and built taking in mind the flexibility in order to be easily adapted to different places. To achieve this, the prototype database has a generic data model and the mobile application takes advantage of a layout that can be used to present information about different places.

In order to help in the content management task, we developed a CMS that can be installed in any Drupal 8 site, providing a way to Smart Place managers to manage the contents displayed through the mobile application, but also allows the managers to access relevant information about statistics of the building performance.

Our prototype, in order to bring more comfort to the building users, has a single mobile application that accesses and shows information about several Smart Places in a common interface design that displays information, that can be translated to meet visitor needs, considering the location of the visitor near each particular interest point, group of interest points or interest zones.

In order to test and validate our prototype, we would like to have done tests in real environments, so we made contacts with some places, but none of them showed availability for us to be able to do it. So, we decided to proceed with some tests based on case studies, namely a Smart Museum and a Smart Mall. For this, we used public information that is available at the shopping mall and museum websites used in this study.

We loaded their information into our prototype, using the Content Management System and defined some interest points, groups of interest points and interest zones based on the building map. Then we configured four BLE devices for the Smart Museum, one identifying an InterestZone, another for a GroupInterestPoints and the other two representing an InterestPoint, each. Also, for the Smart Mall, we configured five BLE devices, three identifying interest zones, which two of them represent the same object to simulate two entries for the same store, and two identifying interest points.

With this, we created a small environment to make some tests and to guarantee that the mobile application presents and stores, in the Smart Place database, the correct information. So, we moved between the BLE devices, that were configured to have a short signal range, to guarantee that the notifications were working correctly, the desired information, from different Smart Places, was presented and the data about the interaction in the environment was well stored in the databases.

Based on the tests made in the controlled space created by us, we identified some limitations and features to be developed in the future to improve the prototype, that we mention in the next section. Despite that, we conclude that the prototype worked as expected in this test environment.

During this dissertation, we published and presented the paper "MOG – A SMART MOBILE SYSTEM FOR INTERACTIVE MUSEUM VISITS", in the MCCSIS 2019, 5th International Conference on Connected Smart Cities, 17 – 19 July 2019 Porto, Portugal [46]. We also submitted a second paper to INTSYS 2019 - 3rd EAI International Conference on Intelligent Transport Systems.

5.1. Future Work

Throughout the development and test phases of this prototype, we identified some limitations and features that can be implemented and released in the future, in order to improve the prototype.

One limitation that we identified is that in the Smart Places list that appears in the mobile application, there is no way to search for a Smart Place, it is necessary to scroll over the list to find the Smart Places, something that can be upsetting. Besides that, every Smart Place is treated the same way and appear with the same format in the list, so one feature that we consider that can improve this prototype is the creation of Smart Places categories. This means that we can create categories like "Smart Restaurant", "Smart Mall", "Smart Store", "Smart Museum", among others, and then group them in the Smart Place list.

Another improvement that we consider important to implement is the representation of the visited spaces on the map. Currently, every space is marked in the map taking into consideration a point and a range, meaning that even if a space, *e.g* an InterestZone, represents a rectangular room, on the map it is represented by a circular shape, what can

be confusing for the users. To improve this representation, each Smart Place could define in the BIM tool the area of each space and extract two types of 2D images to import to our prototype. The first image would be the normal image, that we already use in the Map screen of the mobile application, the other one could be an image with each space marked with a specific color, and map each color with the corresponding space. This approach is similar to the one mentioned in [19] where the authors mark the walkable paths of a building with a color and then in the mobile application, this is read to draw the desired path in the map image.

While creating the data for the Smart Museum and Smart Mall examples, we felt that translating all the available information can be very time-consuming. Therefore, we believe that one improvement to be applied in the prototype would be the integration with a translation API so that the Smart Place managers can get suggestions of translations to their data.

As we already mentioned in section 3.5, chapter 3, our prototype is developed to use just the "onEnter" event of the Proximity SDK, to be simpler to every Smart Place. However, we think it would be important to research ways to take advantage of all events while keeping the prototype simple for the Smart Places and giving them autonomy to define what events they want that each BLE device triggers.

One feature that we believe would bring advantage to the Smart Places is the coordination between our prototype and an Indoor Navigation System, like the Indoor Navigation Systems developed in [32] and [19]. This feature would bring many more possibilities to the Smart Places, like pre-define some routes or even provide to end-users a path to the desired space. Using the Smart Museum and Smart Mall as examples, if the system had an Indoor Navigation System, the Smart Museum managers could define routes that would follow a chronological order, thus improving the visitor's visit experience and for the Smart Mall, this feature could be used, for example, to provide a path to the user desired store.

As we mentioned in section 4.3, chapter 4, the authors in [37] included a profiling feature, something that we consider as being an advantage since it can allow the system to provide relevant information based on data resulting from a profiling process. In our opinion, this feature could also be applied to general Smart Places and not just for Smart Museums as it was used in [37], so we believe that as future work, a research about this feature should be done and used as a complement to our prototype.

One of our concerns in the design and development phase of the prototype was to establish a secure connection with the different Smart Places databases, without exposing the data. In our prototype we used the capabilities of the Firebase API to establish the connections, however, is necessary to allow the mobile application to access information like apiKey and databaseURL. So, we believe that one important work for the future is to research and develop some system in order to guarantee that this type of data is not exposed to the mobile application while keeping it possible to access the databases.

References

[1] "Report: Two-Thirds of World's Population Will Live in Cities by 2050," *US News & World Report*. [Online]. Available: https://www.usnews.com/news/world/articles/2018-05-17/report-two-thirds-of-worlds-population-will-live-in-cities-by-2050. [Accessed: 03-Jan-2019].

[2] "Mobile devices a necessity in today's business world," *TrackVia Blog*, 24-Jun-2013. [Online]. Available: https://www.trackvia.com/blog/infographics/mobile-devices-are-a-necessity-in-todays-business-world/. [Accessed: 05-Jan-2019].

[3] "Museus aumentam número de visitantes em 2016 com ajuda dos estrangeiros | Museus | PÚBLICO." [Online]. Available: https://www.publico.pt/2017/12/12/culturaipsilon/noticia/museus-aumentam-numero-de-visitantes-em-2016-com-ajuda-dos-estrangeiros-1795716. [Accessed: 05-Nov-2019].

[4] M. V. P. Gomes, "Cloud4Things: using Cloud infrastructure to support Smart Place applications," p. 10.

[5] J. Torres-Solis, T. H., and T. Chau, "A Review of Indoor Localization Technologies: towards Navigational Assistance for Topographical Disorientation," in *Ambient Intelligence*, F. J. Villanueva Molina, Ed. InTech, 2010.

[6] "Garmin | What is GPS?," *Garmin*. [Online]. Available: https://www8.garmin.com/aboutGPS/. [Accessed: 12-Jan-2019].

[7] "GPS.gov: Space Segment." [Online]. Available: https://www.gps.gov/systems/gps/space/. [Accessed: 12-Jan-2019].

[8] "WiFi for Indoor Positioning," *Leverege*. [Online]. Available: https://www.leverege.com/blogpost/wifi-indoor-positioning. [Accessed: 15-Jan-2019].

[9] "Understanding RSSI Levels | MetaGeek," *MetaGeek*. [Online]. Available: https://www.metageek.com/training/resources/understanding-rssi.html. [Accessed: 15-Jan-2019].

[10] "Simple questions: What are QR codes and why are they useful?," *Digital Citizen*, 17-Sep-2018. [Online]. Available: https://www.digitalcitizen.life/simple-questions-what-are-qr-codes-and-why-are-they-useful. [Accessed: 14-Jan-2019].

[11] "What is RFID? | The Beginner's Guide to RFID Systems," *atlasRFIDstore*. [Online]. Available: https://www.atlasrfidstore.com/rfid-beginners-guide/. [Accessed: 14-Jan-2019].

[12] "Active RFID vs. Passive RFID: What's the Difference?," *RFID Insider*, 04-Mar-2016. [Online]. Available: https://blog.atlasrfidstore.com/active-rfid-vs-passive-rfid. [Accessed: 14-Jan-2019].

[13] B. Ray, "Bluetooth Vs. Bluetooth Low Energy: What's The Difference?" [Online]. Available: https://www.link-labs.com/blog/bluetooth-vs-bluetooth-low-energy. [Accessed: 14-Jan-2019].

[14] "What are beacons?," *Kontakt.io*. [Online]. Available: https://kontakt.io/beacon-basics/what-is-a-beacon/. [Accessed: 14-Jan-2019].

[15] "iBeacon - Apple Developer," *Apple Developer*. [Online]. Available: https://developer.apple.com/ibeacon/. [Accessed: 14-Jan-2019].

[16] "Eddystone format | Beacons," *Google Developers*. [Online]. Available: https://developers.google.com/beacons/eddystone. [Accessed: 14-Jan-2019].

[17] "Why should I use Proximity SDK? What are the benefits?," *Estimote Community Portal*. [Online]. Available: http://community.estimote.com/hc/en-

us/articles/204100866-Why-should-I-use-Proximity-SDK-What-are-the-benefits-. [Accessed: 14-Jan-2019].

[18]   "Estimote — indoor location with bluetooth beacons and ultra wideband," *estimote*. [Online]. Available: https://estimote.com/. [Accessed: 14-Jan-2019].

[19]   J. C. Ferreira, R. Resende, and S. Martinho, "Beacons and BIM Models for Indoor Guidance and Location," p. 17, 2018.

[20]   "Benefits of BIM | Building Information Modeling | Autodesk," *Autodesk*. [Online]. Available: https://www.autodesk.com/solutions/bim/benefits-of-bim. [Accessed: 20-Jan-2019].

[21]   "Revit For Architecture And Design | Autodesk," *Autodesk*. [Online]. Available: https://www.autodesk.com/products/revit/architecture. [Accessed: 20-Jan-2019].

[22]   "IT faceoff! Cloud hosting versus dedicated server hosting," *MY IT PROS*. [Online]. Available: https://www.myitpros.com/myitpros-blog/it-faceoff-cloud-hosting-versus-dedicated-server-hosting. [Accessed: 24-Jan-2019].

[23]   "Couchbase Mobile – Products | Couchbase," *Couchbase*. [Online]. Available: https://www.couchbase.com/products/mobile. [Accessed: 25-Jan-2019].

[24]   "Mobile App Service | Microsoft Azure." [Online]. Available: https://azure.microsoft.com/en-us/services/app-service/mobile/. [Accessed: 25-Jan-2019].

[25]   "Amazon Cognito - Simple and Secure User Sign Up & Sign In | Amazon Web Services (AWS)," *Amazon Web Services, Inc.* [Online]. Available: https://aws.amazon.com/cognito/. [Accessed: 25-Jan-2019].

[26]   "Firebase," *Firebase*. [Online]. Available: https://firebase.google.com/. [Accessed: 05-Nov-2019].

[27]   "WordPress.com: Create a Free Website or Blog," *WordPress.com*. [Online]. Available: https://wordpress.com/. [Accessed: 31-Jan-2019].

[28]   "Joomla Content Management System (CMS) - try it for free!," *Joomla!* [Online]. Available: https://www.joomla.org/. [Accessed: 31-Jan-2019].

[29]   "Drupal 8 is here," *Drupal.org*, 17-Nov-2015. [Online]. Available: https://www.drupal.org/8. [Accessed: 31-Jan-2019].

[30]   "CMS comparison: A review of the best platforms," *IONOS Digitalguide*. [Online]. Available: https://www.ionos.com/digitalguide/hosting/cms/cms-comparison-a-review-of-the-best-platforms/. [Accessed: 15-Feb-2019].

[31]   "PHP: What is PHP? - Manual." [Online]. Available: https://www.php.net/manual/en/intro-whatis.php. [Accessed: 05-Nov-2019].

[32]   U. Rueppel and K. Stuebbe, "BIM-Based Indoor-Emergency-Navigation-System for Complex Buildings," *Tsinghua Sci. Technol.*, vol. 13, Oct. 2008.

[33]   G. Tabunshchyk, D. Merode, Y. Goncharov, and K. Patrakhalko, "SMART-CAMPUS INFRASTRUCTURE DEVELOPMENT BASED ON BLE 4.0," May 2015.

[34]   M. Choi, W.-K. Park, and I. Lee, "Smart office energy management system using bluetooth low energy based beacons and a mobile app," *2015 IEEE Int. Conf. Consum. Electron. ICCE 2015*, pp. 501–502, Mar. 2015.

[35]   A. Corna, L. Fontana, A. Nacci, and D. Sciuto, "Occupancy Detection via iBeacon on Android Devices for Smart Building Management," 2015.

[36]   T. Ishida, Y. Shinotsuka, M. Iyobe, N. Uchida, K. Sugita, and Y. Shibata, "Development of a Zoo Walk Navigation System using the Positional Measurement Technology and the Wireless Communication Technology," *J Internet Serv Inf Secur*, vol. 6, pp. 65–84, 2016.

[37]   S. Alletto, R. Cucchiara, G. Del Fiore, L. Mainetti, L. Patrono, and G. Serra, "An Indoor Location-Aware System for an IoT-Based Smart Museum," *IEEE Internet Things J.*, vol. 3, Apr. 2016.

[38]   A. Chianese and F. Piccialli, "Designing a Smart Museum: When Cultural Heritage Joins IoT," in *2014 Eighth International Conference on Next Generation Mobile Apps, Services and Technologies*, 2014, pp. 300–306.

[39]   "CMS for Museums," *izi.TRAVEL Help*. [Online]. Available: https://academy.izi.travel/help/production/cms-for-museums/. [Accessed: 22-Jan-2019].

[40]   Blaz, "Automatic Museum Guide," *Locatify*. [Online]. Available: https://locatify.com/automatic-museum-guide/. [Accessed: 22-Jan-2019].

[41]   E. S. Bae, D. U. Im, and S. Y. Lee, "Smart museum based on regional unified app," vol. 7, pp. 157–166, Jan. 2013.

[42]   "Firebase Realtime Database | Store and sync data in real time," *Firebase*. [Online]. Available: https://firebase.google.com/products/realtime-database. [Accessed: 25-Jan-2019].

[43]   "How tags & attachments work in Proximity SDK," *Estimote Community Portal*. [Online]. Available: http://community.estimote.com/hc/en-us/articles/360006978891-How-tags-attachments-work-in-Proximity-SDK. [Accessed: 10-Feb-2019].

[44]   "Museu Nacional de História Natural e da Ciência | TODO O UNIVERSO NA CIDADE." [Online]. Available: https://www.museus.ulisboa.pt/. [Accessed: 22-May-2019].

[45]   "Surrey Quays Shopping in Rotherhithe, London | Shops & Restaurants," *Surrey Quays Shopping in Rotherhithe, London | Shops & Restaurants*. [Online]. Available: https://www.surreyquays.co.uk/. [Accessed: 31-May-2019].

[46]   B. Coitos, C. Serrão, and N. Garrido, "MOG - A SMARTMOBILE SYSTEMFOR INTERACTIVE MUSEUMVISITS," 2019, pp. 191–198.