TÉCNICO LISBOA

A Day at Tecnico's Computation Museum

IoT to Support Escape The Room and Treasure Hunt Games

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Abstract

Museums are becoming increasingly disconnected with people's way of consuming entertainment. In the age of interactivity and instant feedback, museums must strive for the digital transformation that's happening everywhere. A way to tackle this is to try and incorporate digital devices into the museum that can enhance visitor's experience.

To accomplish this we developed an escape the room and infrastructure to be deployed in the museum. This infrastructure will manage several components of our solution as well as the game itself. We developed the escape the room in a modular fashion where we simply developed interactions that we then used in coordination with each other to create the game.

The results achieved show that we managed to enhance visitor's experience and motivate them to return to the museum due to the enjoyment they felt playing our game. On this note we also managed to validate that our infrastructure is able to support our game making use of very affordable hardware. We also saw that using the interactions in the context of the escape the room proves to be more enjoyable for visitors than using them individually.

To conclude, gamifying the museum through an escape the room produces positive effects on visitor's enjoyment, is an effective way of enhancing their experience and motivates people to return. This, in turn, signifies that our solution was able to tighten the gap between current generations and museums and provide a clear path for the latter on how to perform this digital transformation.

Keywords

Internet of Things; Escape The Room; Museum; Smart Museum; Serious Games; Gamification;

Resumo

Os museus estão progressivamente mais desconectados com a maneira como as pessoas consomem entretenimento. Na era da interatividade e feedback instantâneo, os museus devem lutar pela transformação digital que está a ocorrer em todo o lado. Uma maneira de combater isto é tentar e incorporar dispositivos digitais no museu que possam melhorar a experiência dos visitantes.

De modo a conseguir isto, nós desenvolvemos um escape the room e infraestrutura para serem implantados no museu. Esta infraestrutura vai gerir diversos componentes da nossa solução assim como o próprio jogo. Nos desenvolvemos os escape the room numa maneira modular onde simplesmente temos de desenvolver as interações que depois usamos em coordenação umas com as outras para criar o jogo.

Os resultados atingidos mostram que fomos capazes de melhorar a experiência dos visitantes e conseguimos motivá-los a regressarem ao museu devido ao prazer que estes sentiram enquanto jogavam o nosso jogo. Também conseguimos validar que a nossa infraestrutura é capaz de suportar o nosso jogo fazendo uso de hardware muito barato. Também observámos que usar as interações no contexto do escape the room mostra ser mais prazeroso para os visitantes do que usá-las individualmente.

Para concluir, gamificar o museu através de um escape the room produz efeitos positivos no prazer dos visitantes, é uma maneira eficaz de melhorar a sua experiência e motiva as pessoas a voltarem. Isto, por consequente, significa que a nossa solução foi capaz de diminuir a lacuna entre gerações atuais e os museus e providenciar um caminho claro para os últimos sobre como devem realizar esta transformação digital.

Palavras Chave

Internet das Coisas; Escape The Room; Museu; Museu Inteligente; Jogos Sérios; Gamificação;

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Listings

Acronyms

AR	Augmented Reality
BCI	Brain Computer Interface
BLE	Bluetooth Low Energy
BYOD	Bring Your Own Device
CHM	Computer History Museum
GUI	Graphical User Interface
GPIO	general purpose input/output
IST	Instituto Superior Técnico
LCM+L	Living Computers: Museum + Labs
LF	Low Frequency
MVC	Model-View-Controller
MCU	Micro Controller Unit
NFC	Near Field Communication
ORM	object–relational mapping
PRS	Peddy-Room System
PoC	Proof of Concept
QR	Quick Response
RFID	Radio Frequency Identification
SBC	single-board computer
TNMOC	The National Museum of Computing
UHF	Ultra High Frequency
UK	United Kingdom
US	United States

VR Virtual Reality

1

Introduction

Contents

How well can museums survive in an age where knowledge, entertainment and overall people's lives are becoming ever more digitized? This questions is becoming more relevant as time goes by since we can observe that museums, almost like the artifacts they preserve and exhibit, are becoming part of history when it comes to the way they deliver content to their visitors. As it's known, museums have a unique approach when it comes to teaching history to the masses since they possess artifacts that visitors can connect to when learning about certain subjects, making their experience and their learning more in contact with past reality than any other medium can.

Even though museums have these characteristics that makes them stand out when compared to other mediums, it still does not rule out the fact that they are endangered by the ever more digitized society we live in. The reason why this is threatening museums is mainly related to the fact that museums still deliver content to their visitors without making use of many or any digital means. Consequently this creates a considerable generational gap between the way museums deliver their content to visitors and the way the latter are used to consuming it. This, in turn, leads to people of generations that have technology as an integral part of their lives for either work, entertainment and other purposes as well, to have a less enjoyable or even bad visiting experience when exploring museums that don't make use of technology or don't possess such an option to deliver their content.

Taking all into consideration, the question that arises is if the integration of technology in a museum environment would tighten the generational gap that keeps growing over time. More specifically, what if this integration would take the form of an escape the room that is to be played in the museum by making use of digital means? The games industry is one of the biggest industries in the world and nowadays people of all age groups play games in one or even many types of different devices which leads us to believe games are the most adequate bridge to reduce or even eliminate the gap that has been established between museums and recent generations of visitors that make avid use of digital devices.

As established, we believe that games are the bridge to tighten the generational gap and we intend to use an Escape The Room to try and prove through it that visitor's experience, both learning and visiting, can be enhanced with it. Escape The Room games are becoming more popular over the years and are the ones, due to the way they are played, that fit perfectly with the context of a museum. These games rely on the resolution of riddles and discovery of clues to be completed and this fits perfectly with a museum since by leveraging the puzzles that make up this game we can integrate the usage of digital devices for the acquisition and delivery of content.

In the end, we will be developing a support infrastructure to support the escape the room we will also be developing and that will allows us to determine if the integration of games and digital devices in the museum contributes to creating a better visiting and learning experience and tighten the generational gap between people that are more used to digital devices and people that are not familiar with them.

1.1 Problem Statement

Digital Transformation has been one of the main obstacles for museums since technology is becoming, more than ever, an integral part of people's lives. In fact, almost half of the world population owns a smartphone and this value is expected to increase to the point that by 2021 3.8 billion people will own one [1]. Digitization is occurring in many areas of people's lives but, not all of them are being particularly affected by this revolution. The physical book market, for example, is still stronger sales wise when compared to eBooks which were supposed to bring about a revolution that would make physical book sales decrease with time. This shows that, even though this digital revolution is taking place in many areas, not all of them are being affected by it and hence do not feel the need to make this transition to digital.

One could argue that museums are not being affected by this digital revolution since data [2–10] shows that museums are experiencing a really high number of visitors, in many cases the highest number ever registered in the last years, and changing the way people interact with museums and exhibits can actually cause more prejudice than benefits. Except that, if we analyse the data and see the demographics of the visitors, we see that the majority of people attending museum exhibitions are over 25 years of age while those aged between 16 and 24 are almost the smallest percentage of visitors in the museum surpassed only by those aged above 75 years.

Figure 1.1: Digital Transformation challenge to overcome

This decrease in visitors of younger ages can lead to serious problems in the future in terms of attendance since people will become disconnected from museums (and vice versa) and consequently more disconnected from history and its numerous artefacts which, in turn, might threaten the existence of these sites due to the lack of revenue brought about by the lack of visitors.

This issue is the one which this work will be focused on solving, **tightening the gap between current and future generations through the usage of technology to enhance visitor's experience in the museum**. This attempt at solving this problem is aligned with the suggestions [8, 11, 12] that state that we should push forward in the direction of digitizing museums in regards to making the experience for visitors more digital based.

When attempting to solve the aforementioned problem, there are other issues that revolve around

it which we will need to have into consideration when developing our solution. One of these issues, for example, is related to how we will integrate technology in museums since the usage of games to achieve this can bring other problems like the disregard for the educational component that museums should have towards the community. This, alongside other obstacles like those in fig. 1.2, will be the subject of analysis this section so that we can fully understand the dimension of the issue we will be tackling with our solution alongside all of the factors we have to take into consideration when designing it.

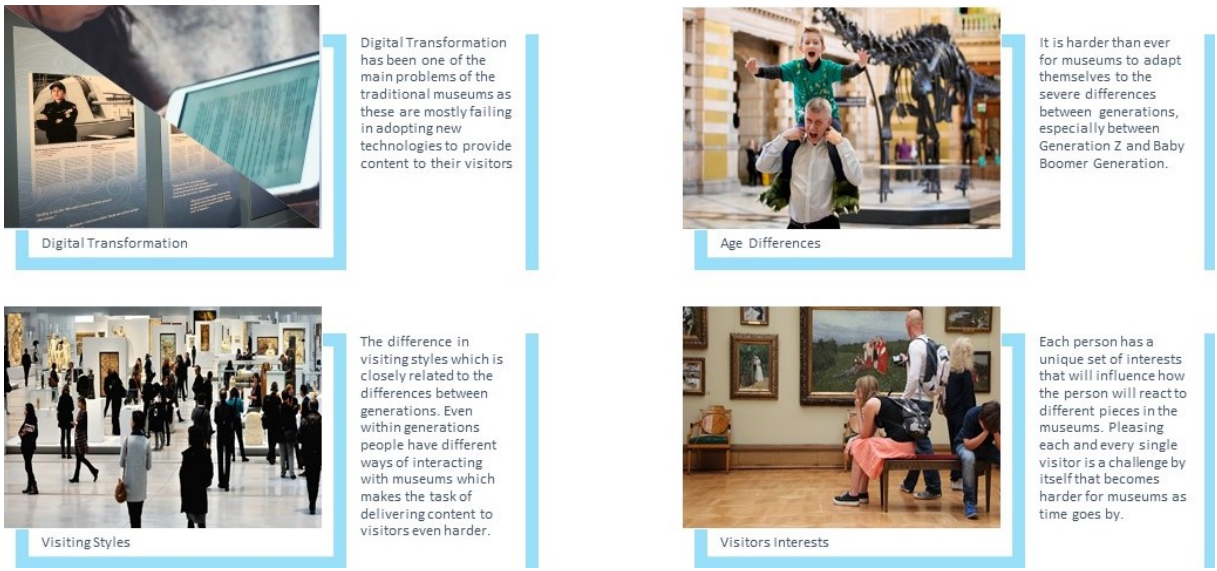

Figure 1.2: Challenges museums face nowadays while trying to teach and entertain their visitors.

When attempting to tackle our main issue, age is one of the factors to have into consideration, especially when developing a game to be used for the effect of enhancing visitors experience. This is due to the fact that different age groups are characterized by different interests and these differences can be seen in the demographics of visitors since the majority of people visiting museums are aged above 25. One approach that tried to tackle this issue was the creation of museums aimed at younger audiences but this is not adequate if we want to make regular museums attractive for audiences of all ages. So, the question arises, which is, **how do we make museums a fun, inclusive and interesting place for people of all age groups** without having to create museums aimed specifically at different age groups.

Another challenge we will analyse later in this work is the fact that each person has its own visiting style which means that everyone has a different way of interacting with exhibits, either by taking a closer look at them and taking their time to acquire knowledge about artifacts while others just like to take an overview of the museum, rarely approaching any item in exhibit. The way exhibits are made promote a visiting style that fits the people of the former style while the latter are deprived of a lot of content that

they choose not to take a closer look at which, in return, deprives them of having an experience as great and entertaining. This issue was the subject of some studies [13–15] that enlighten the positive results of approaches that favour both visiting styles but, simultaneously, state that this subject of alternative interaction forms has received little attention.

One final challenge that must be considered is the environment where the solution is going to be deployed. In our particular case, a museum is a challenging place to deploy a solution like ours since we must always account for one of the most important aspects of a museum which is, besides being a place for entertainment, it is mainly a place of knowledge. This is a challenge because it implies very careful planning and design of our solution since if this hard to achieve balance between education and entertainment is not met we risk having a solution that either entertains visitors without teaching them anything or fail to amuse them, maybe even bore them.

Having the previous into consideration we will try to discover the impact of implementing an infrastructure that will support an Escape The Room game that will leverage the use of digital means to be played, so we can see if it's feasible to implement such a game to be used to explore the Computation Museum at Instituto Superior Técnico without negatively impacting user experience. Additionally, we'll investigate the users perception to the adoption of this approach and, determine whether they are open to visit museums that implement similar solutions based on games and digital means (such as mobile phones, videos, audios, and other technologies). This proposal of ours sheds light onto an important question which is **How can games be integrated into a museum context to enhance visitor's experience?**

1.2 Motivation

Winston Churchill once said, in an attempt to quote George Santayana, that 'Those who fail to learn from history are condemned to repeat it.'. This sentence, alongside the one from Robert Heinlein 'A generation which ignores history has no past and no future.', illustrates the importance that history has in shaping the future as it's a record of all lessons mankind has learned. These two quotes can be considered enough to showcase the importance that museums, as mediums to teach history, have in preventing current and future generations from committing past mistakes and to learn and inspire themselves from that same past in order to shape the future. This work represents a step forward in making the necessary adjustments to the way people interact with museums and their exhibits in order to motivate current and younger generations to have it as an habit to visits museums as they shall start being associated to words like "Games" (Serious Games) and other interests of these generations.

Even though this work is centered around museums, we cannot disregard that other history teaching mediums exist and that have their own characteristics that differentiate them from museums. The latter

are unique in the sense that they can showcase the historical items, or historically accurate replicas, while educating people about them but how do museums compare to other mediums such as books, documentaries, etc.? In order to answer this question we decided to conduct a simple survey that asked three questions:

- What is your preferred medium to learn history?
- Which medium provides you the most fun when learning history?
- Which medium motivates you the most to learn more about history?

Respondents had five different types of mediums as options which were museums, books, documentaries, the internet and school. After having collected 38 answers from people whose gender and age distribution can be seen in fig. 1.3a and fig. 1.3b respectively we concluded that museums are currently failing in being the best at any of the three purposed questions.

(a) Gender distribution of survey respondents.

(b) Age distribution of survey respondents.

Figure 1.3: Demographics of survey respondents.

Taking a closer look at the results of the surveyappendix A we see that, regarding respondents preferences, the most preferred medium to learn history is the internet followed by documentaries and only then museums. Both mediums that have an average value bigger than museums have one common characteristic, which is the fact that both are digital based with the internet having as support devices computers, smart phones and tablets and documentaries having all of the previous as well as television. Museums, Books and school/courses are mediums that don't make use of almost any digital device and therefor are nowadays more disconnected from the current generations, hence being less preferable to them. These results maintain themselves for the following questions where we can see that in terms of fun and motivation to learn more about a certain historical subject, the internet and documentaries remain with the first and second highest averages respectively and museums remain as the third highest average. These results are on par with those reported by one study [16] that highlights the barriers to visiting heritage sites. It shows that the second highest reason for not visiting is the lack of interest which corresponds to 36% of responses, just 1% below the top reason which is lack of time. Similar results are found in another study [17] from the EU Commission that shows again that the main reason for not

participating in cultural activities like going to museums is mainly due to lack of interest towards these sites.

We can now see another issue that this work will allow us to tackle which is reducing the amount of people that choose ”Lack of interest” as a barrier to not visiting cultural sites. The way we'll achieve this will be detailed later in this document but we can state that it will meet the conclusions of several studies [18, 19] that state that digital technologies have a central role in marking the change that needs to happen for cultural spaces to innovate and attract newer and younger audiences. With this premise in mind, we developed a system that allows for a continuous integration of newer and diverse technologies so as to support other works that can take place in the museum, drawing special attention to ways of **evaluating learning performance of visitors** through the use of serious games and interactions with hopes of contributing to the standardization of learning performance variables. Not only this but to also foster the development of applications/studies that use technologies such as Brain-Computer Interfaces (BCIs) [20–22], Bluetooth Low Energy Beacons for, for example, indoor localization [23–26] and others.

The introduction of digital technologies in a museum environment also allows us to leverage our system to turn the museum into a smart environment [27,28] by employing several sensors that shall monitor relevant variables (light, temperature, noise, humidity and others) which are important for museum staff to have under control in order to preserve an optimal environment inside the museum. Consequently, museums will have a better understanding of their areas in terms of hours of most/less noise, hotter/-colder rooms, etc. which, in turn, will lead to a better management of their own spaces.

Lastly, we achieve all of this without the use of powerful hardware or expensive equipment since this would discourage museums from adopting such a solution. In fact, we will achieve all of the previously mentioned goals using only several single-board computer (SBC)s, namely the Raspberry Pi 3, and Micro Controller Unit (MCU)s like the Arduino Nano and Uno. Using only these devices we will develop an affordable, expandable, modular and reliable system that will support an escape the room game and that will allow us to achieve all of the features previously mentioned and that is prepared to foster other works in the future.

1.3 General Solution

The way we intend to achieve our main goal of enhancing the museum experience for visitors through the integration of digital technologies in the museum is by using these in an Escape The Room game that we will create to be played in the museum. This is done by having several SBCs scattered across the museum, designated throughout this work as **Interaction Pi's**, and connected to these Interaction Pi's we'll have MCUs running mini-games (We call these interactions). Separating the interaction logic that takes place in the MCU from the system logic that happens in the Interaction Pi we are able to achieve

a bigger degree of modularity which consequently will allows us to add, remove and modify interactions independently of the rest of the system. Additionally, through this separation of responsibilities, the limited resources of each device are used to the best of their extent and the load on each one is smaller making it so that the Interaction Pi has to concern itself with only computing intensive tasks while the MCUs handle the controlling and sensing tasks.

The Escape The Room is composed by several interactions that are connected to the Interaction Pi's via a USB connection. The administrator of the system manually configures and adds interactions to the Interaction Pi's through their management page which can be accessed via network from a central Raspberry Pi which we designated as **Master Pi**. Once everything is ready for the Escape The Room to commence, the game can be started from the afore mentioned Central Pi and it will take place for at most one hour. During execution of the game, visitors will have the opportunity to explore the museum and learn by solving the interactions until they finally solve all of them or run out of time.

Achieving all of the objectives that we set for this work involved using technologies that would allows us to create interfaces that an average user would be able to use to navigate the system and it's functions and, perform the management tasks, alongside the monitoring ones, that we mentioned previously. Simultaneously, we needed to be sure that these interfaces could be accessed from a central computer (The Master Pi) so that each device could be individually managed with ease. These requirements, alongside the one of having a solution that does not require devices of high computational power (since we are limited to the power of the Raspberry Pi 3 Model B), are achieved by employing the most popular Java framework, the Spring Framework. Using Spring allowed us to implement a web interface that is used to manage all of the Interaction Pi's, interactions and sensor without it putting a severe load on the Raspberry Pi. Alongside Spring we employed several other technologies that are used to communicate with the micro-controllers, to deploy and manage the several databases that we require to persist data, among many others that we shall discuss later in order to understand their role and importance in our solution.

1.4 Main Results and Findings

When it comes to the results we were able to achieve using our solution, we collected two different sets of results that are important to mention. The first set was regarding the interactions which had to be individually validated with the users in order to understand if they were working properly and were properly designed and ready to be used in the escape the room. Not only did we acquire confirmation of these points, but we also saw that users found it enjoying to use these interactions and felt that they enhanced their experience to the point where they felt motivated to visit museums that featured such interactions.

When it comes to the escape room we developed, we saw very good results as well with the majority of people having enjoyed the game even though more than half were not able to successfully finish it which tells us that even though the difficulty might be high, users still managed to have a good time to the point where they felt motivated to return and replay the game.

The subject of the different visiting styles that we saw previously was also one we approached in our solution and was one that was positively received by our users as they stated that this diversity positively contributed to their experience. In the end we were able to achieve positive results that allowed us to validate all of the theories we set out to validate using our solution.

1.5 Document Structure

We will start this document by first, in chapter 2, taking a look at studies and scientific articles that will give us relevant insights on data that we will use to shape our solution and guide the way we develop all parts of it, from the infrastructure, interactions and all the way to the escape the room. Following this, in chapter 3, we will detail the architecture we designed and explain the logic that is behind the entire system as well as the escape the room so that we can then, in chapter 4, document how we took all of the concepts of chapter 3 and implemented them into our actual solution, talking about general options all the way to the key components of our solution such as the relevant processes and the interactions and escape the room.

We will then see, in chapter 5, the results collected by our solution and discuss them to draw relevant conclusion for our work that allow us, or not, to validate our hypothesis and we will finish, in chapter 6, by drawing conclusions on the overall work and planning our work for the future in terms of improvements that need to be made to accommodate for user feedback.

2

Related Work

Contents

Our approach is not the first attempt at solving the challenges stated in section 1.1. In fact, there have been several others that tried to solve our main issue of revolutionizing the way people interact with museums, some of which have actually been implemented and deployed in museums similarly themed to the Computation Museum at Instituto Superior Técnico. Those approaches, which we will analyze in the following sections, have inspired this work and motivated the implementation of several features that comprise our solution and also allowed us to support the claim that alternative ways of interacting with museum exhibits actually benefit museums and it's visitors. By analysing museums that are pioneers in terms of adopting the use of digital technologies as ways of innovating and adapting the experience to the growing number of digital natives and digital immigrants we will be able to understand what is currently being made to revolutionize visitor's experience and how those solutions match or differ from our own.

Whilst taking advantage of the previous analysis of pioneer museums, we'll also be studying some of the possible interaction types that are able to be used in a museum context so as to give another dimension to visitor's experience. When discussing the types of interactions we'll also examine fairly recent studies that were focused around the effects of using those types and determine their main outcomes to understand how viable those types of interactions are to be placed within the context of a museum.

Furthermore we'll try to understand what technologies comprise the afore mentioned interactions to see what is expected from a system like ours in terms of technological support/compatibility. This will help understand what are the most common types of technologies that are being deployed in museums and their purposes.

2.1 Interactive Museums

The museums that we have studied were the **Computer History Museum** [29], **The National Museum of Computing** [30] and the **Living Computers Museum + Labs** [31]. All of the previous are similarly themed to the Computation Museum at Instituto Superior Técnico where our system will be deployed and the Escape the Room take place. This way we can get a better understanding of what similar museums to the one where we will be deploying our work are doing in order to push forward towards the digital transformation of their spaces and exhibits.

2.1.1 Computer History Museum - CHM

The Computer History Museum (CHM) houses, what it claims to be, "the largest and most significant collection of computing artifacts in the world" [32] and was one of the studied museums due to it's advances in including digital means to transform and revolutionize visitor's experience.

CHM achieved this transformation by **1.** creating dedicated spaces for visitors to interact and get a hands-on approach at some of the subjects that the museum is trying to teach (programming, assembling/disassembling computers, etc.), by **2.** promoting workshops and lectures where visitors are involved in discussions/debates, by **3.** having tablets scattered throughout the museum that allow visitors to get to know some of the items in exhibit via videos, images and audio formats accompanied by text and lastly by **4.** eliminating the physical and geographical barriers of the museum by having a virtual replica of it available online for people to visit.

It now becomes evident that there has been a major effort on several fronts by the museum to transform itself and start connecting with more audiences that possess different interests and are familiarized with different devices. The inclusion of tablets around the museum that visitors can interact provides other media formats (audio, images, video and even virtual reality) which they might prefer over the regular text plates, or even be more familiarized with, in order to get more involved with the exhibits and acquire a deeper understanding of them. Additionally, the workshops and dedicated spaces for the occurrence of activities where visitors have to get involved also increases the interactivity between them and subjects related to the museum, conferring a practical dimension to the visit.

Besides these on-site approaches, the adoption of Virtual Reality (VR) to create a replica of the museum- fig. 2.1 as an ”alternative” (The use of a virtual replica of the museum is not a viable alternative to the live visits, in our perspective, since many information cannot be read and other features available on site do not have a virtual equivalent) to live visits is also another feat that this museum has achieved. This technology has been used in other studies [33, 34] for similar purposes which is that of creating a virtual museum to replace, or serve as an alternative to, physical museums so that the geographical and physical barriers to visiting cease to exist. The previously mentioned application of VR is not relevant for this work since we intend to integrate technology into the museum and not use it to replace it entirely.

Figure 2.1: Screenshot of the virtual tour of the Computer History Museum showcasing the use of tablets and screens.

2.1.2 The National Museum of Computing - TNMOC

Regarding The National Museum of Computing (TNMOC), this is an example of another museum centered around computers and computation in general that has also made use of technology to enhance

the visitor's experience. Similarly to the CHM, we can see the adoption of VRfig. 2.2 to provide a virtual tour to people that are not able to visit the museum (at the time of writing, due to the COVID-19 pandemic restrictions) or prefer to do so from the comfort of their home. Furthermore, another similarity that can be observed between the two museums is the dedicated space for activities that are more interactive/practical. TNMOC has a space designated as "The Classroom" where visitors can interact with legacy machines (usually on display) to learn programming or to simply interact with these machines to get a feel for what they were like when they were state of the art hardware. This is, again, a different approach than ours to the objective of enhancing the museum experience since this space is dedicated to learning and giving visitors a more interactive experience with the subjects/machines which they are learning about while our approach makes the entire museum, not one or two areas of it, an interactive experience.

Figure 2.2: Screenshot of the virtual tour of The National Museum of Computing where the PC Gallery with some working computers can be seen.

Yet, there are two galleries of the museum that are part of the spaces dedicated to discovering and visualizing items in display, and not necessarily learn something about them (like "The Classroom" gallery), that feature interactive pieces in display for people to use. These galleries are the "PC Gallery", the "Simulation Gallery" and the "Air Traffic Control" which feature old computers set up with popular games of the time, old arcade games of the 1980's and, still under development, a simulation of air traffic control respectively. Displaying pieces that are available for people to interact with comes closer to what we're aiming to achieve with our approach since the museum itself becomes a more playful place that is able to please people of all ages as such.

2.1.3 Living Computers Museum + Labs - LCM+L

The Living Computers: Museum + Labs (LCM+L) provides several exhibits with interactive and immersive elements that visitors can explore during their visit. It's the only museum, of the three, that introduced on-site VR and Augmented Reality (AR) devices that people can use to understand the possibilities they offer and how they operate in order to provide such experiences. Furthermore, the LCM+L also provides workshops and educational resources for people to experience and learn either within the

museum, through workshops in game making, or outside the museum, with tutorials and video courses that teach people how to program or give them a hands-on approach to legacy systems via emulators.

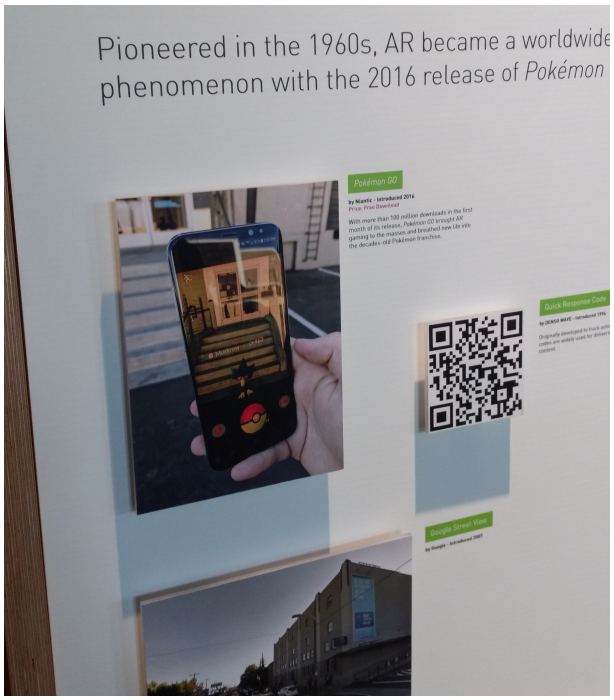

Figure 2.3: Augmented Reality exhibit in the LCM+L (Source: LCM+L Twitter)

All of these contemporary museums, that are striving to implement technological based solutions to revolutionize the way people interact with their exhibits, showcase that games, educational content such as workshops and virtual replicas of the museums themselves are somewhat of a common approach that these museums have taken. Although this can be considered a positive evolution when compared to text plates and/or pamphlets, one could argue that these formats are present due to the context of the museums (A computer/computation museum where games are part of the theme) where they are present. Additionally, the virtual replicas of the museums do not enhance the experience for in-person visitors and the workshops/educational content that museums provide are separate activities from the actual visit.

It's now clear that museums are fighting to stay relevant in an ever more digital era by attempting to connect with people on-site and especially at home through the use of online platforms that give a small sample of what the museum experience might feel like and what people can learn there. On the other hand, the focus on on-site visitors needs to be bigger and employ solutions that do not limit themselves to the context of just some museums. For this reason, we will discuss some types of interactions that are not limited to the context of the museum (like games did in all the previous examples) and that can bring some major changes to museum visits.

2.2 Types of Interactions

Previously, we analyzed some of the technologies and interactions that are currently being used by museums themed similarly to the Computation Museum at Instituto Superior Técnico and we stated that those mentioned interactions/technologies were not focusing themselves on the visitors that are traversing through the museum and served more as a complement/alternative to live visits. Taking this into account, we will analyze some types of interactions that are integrated into museums and that have been tested in several studies so as to understand what are the positive and negative impacts that the use of said interactions may bring about to the museum and its visitors.

2.2.1 Serious Games

The first interaction type are **Serious Games** as these have been subject of many studies regarding gamification and it's benefits/drawbacks when applied to different areas such as education, training, health, etc.. Before analysing some studies that discuss the effects of the use of serious games in a museum context, we should first answer the two main questions that arise when discussing this subject which are, **"What are serious games and how do they differ from regular games?"** and **"What is gamification?"**.

Regarding the first question, there are many definitions for serious games but, the one we chose as the most appropriate is "any piece of software that merges a non-entertaining purpose (serious) with a video game structure (game)" [35]. This definition clearly states what is the difference between the games that we could observe in section 2.1 (regular games from different time periods whose purpose there was to provide some degree of interactivity to visitors while showing them how games were) from Serious games that have an additional purpose besides entertaining visitors, which is educating them.

Commonly associated to the concept of serious games, the concept of **gamification** is a key concept of our work and, consequently, there is a need to clarify what does it stand for before analyzing the studies that make use of serious games. Gamification also has several definitions but the one we found the most adequate in the context of our work is **The process of enhancing user engagement with a product or service through the use of gameplay elements in non-gaming settings in order to support user's overall value creation** [36, 37].

Following the clarification of the two previous questions, we can now analyze some studies whose objective is to conclude the outcomes of deploying a serious game in the context of a museum so that we can understand the advantages and drawbacks of this type of interaction when used in a context similar to ours. We begin with a serious game that was deployed in the Natural History Museum of Funchal, Portugal, called **The Ocean Game** which aimed at assessing the engagement and learning of children aged between 9 and 10 years old through the use of a mobile based treasure-hunt game. The

findings this study achieved show many advantages of a gamified approach to a museum visit, one of which was the fact that younger audiences actually prefer to explore and enjoy the museum through a gamified approach when compared to a traditional guided tour. Additionally, it also highlights some of the advantages of mobile based approaches in creating a more interactive museum experience since these types of interactions require very few or no changes to the exhibition spaces and it is a type of interaction that visitors of almost every age group are familiarized with. Regarding the game and its ability to achieve the goals it was set out to achieve, the researchers that conducted this study found that children that explored the museum using the Ocean Game "were immersed, engaged and motivated" in playing it and stated that they would like to return to replay it but to learn about new animals.

The acquired data also allowed researchers to conclude that, in comparison to traditional guided tours, the Ocean game was more enjoyable and engaging but did not support rich social interaction amongst children. Besides the previous and, in accordance with another study [38], researchers also found that "museum exhibitions are positively affected by the introduction of ubiquitous games and information systems.". Concerning drawbacks, special attention is drawn to the fact that when designing a serious game, the educational and entertainment aspect of the game must be balanced appropriately so as not to neglect that a museum is a site dedicated to educate people about history. Failing to do so may lead the game to be either disproportionately educational or entertaining which may lead to boredom or lack of educational achievement respectively.

Another study [39], which focused on the general topic of "Learning cultural heritage by serious games", showcases, amongst many relevant pieces of data, the challenges of deploying serious games in a static location such as a museum. They reference the fact that these spaces "have strict space and time constraints" which in turn leads them to state that when deploying such types of interactions in a museum, these should have a gameplay that is "immediate, with no need for tutoring" so that visitor's queues can be avoided. An alternative to avoid the previous problems is the development of serious games with a multi-player architecture so that several people can play simultaneously.

Given the previously analysed studies and others [15,40–42], serious games have an already proved potential of enhancing the museum experience even when they are used to extend visitor's experience beyond the actual museum itself. This interaction type is also characterized by challenges of its own, namely the fact that, given its nature, one cannot neglect the educational aspect that comprises a serious game while not allowing this component to subdue the entertainment one and vice versa. Furthermore, the context where serious games are inserted into add challenges of their own since spaces like museums have a high affluence of visitors that makes it nearly impossible to deploy a game that takes a long time to be played or understood making it inadequate to be placed in a space where high visitor count is to be taken into consideration. The main takeaway is that serious games, when developed appropriately, are an appropriate type of interaction to have in a cultural heritage context, like a museum, since they

are able to provide the sought out entertainment component that visitors crave for when visiting a cultural heritage site while at the same time educating said visitors.

2.2.2 Tangible Interactions

Tangible Interactions is a general but misleading term that we use in this section to categorize interactions that a user can physically interact with by means of, for example, RFID/NFC cards, touch sensors, pressure sensors and others that can be seen in fig. 2.4. The reason why we state this term is misleading is due to the fact that a mobile device, like a smartphone or tablet, is also a tangible interaction in the sense that a user needs to physically interact with it in order to use it. Here we will focus on the dichotomy between mobile devices (finger interaction on the phone) and what we consider to be tangible interactions (tangible manipulation) used in the context of a museum. This topic was brought to our attention in a study [13] where the use of smartphones is compared to the use of tangibles (Smart cards and smart replicas) as means to interact with a museum exhibit so as to discover which of these two types of devices visitors would prefer, like/dislike the most to use and the reasons behind their choice.

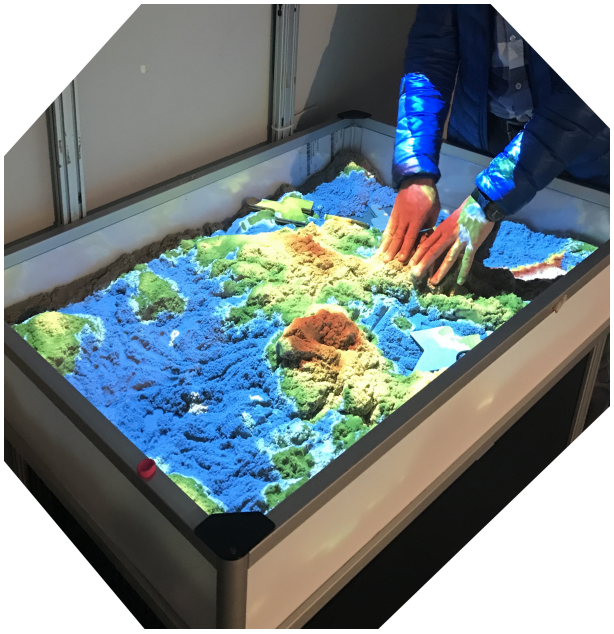

Figure 2.4: SandScape device installed in the Children's Creativity Museum in San Francisco (Ilya.osipov, 2017, Image downloaded from https://en.wikipedia.org/wiki/Tangible_user_interface in May 2021.)

2.2.2.A The Phone

Nowadays, some museums provide dedicated apps to be used during the exhibit that allow visitors to consult maps of the exhibit and have access to other forms of media that can enhance the on site information. Development of these apps is a challenge by itself since the type of app also plays an important

role for the visitor. These apps are generally of the informative type (layout of the exhibition, information regarding the pieces in exhibit themselves, etc...), making it so that there is little to no investment in other types of apps such as those that can provide other forms of entertainment like AR and VR for example.

The results show that the phone, of the three interactions, is the most disliked one among the 76 visitors that took part in the study, stating a clear preference for tangibles (60%) over mobile devices (40%). However, there is the assumption that visitors of younger ages are more prone to prefer mobile devices over other interaction types and so, in order to understand if this assumption would be verified in the results of the study, researchers proceeded to test the hypothesis against their results of whether or not younger people are more likely to prefer the phone than elderly people, only to discover that the preference for a specific type of interaction does not depend on the age of the person. In fact, it was found that the reasons for preferring the phone were the fact that it **allowed free movement while listening**, **the provided headphones cancel the background noise**[1] and that **there was no need to wait for an interactive station**. On the other hand, the two main reasons behind phone disliking were that it **isolated the visitor** and it **distracts from the exhibition**.

These results show that the phone, as an interaction to be used in the museum, favors mobility and gives visitors the ability to enjoy their visit without having to deal with queues. Nonetheless, it is also considered a source of isolation and distraction. Finally, the phone was found to be the most preferable type of interaction for people that fit the Fish category [43] something we will analyze later in section 2.2.2.D.

2.2.2.B Bring Your Own Device Approach(BYOD)

Related to mobile devices, in particular smartphones, is the Bring Your Own Device (BYOD) approach which is, as the name indicates, an approach where institutions rely on people, the visitors, to bring their own devices to be used in a activity. This subject is also discussed in the study with the intent of shedding some light on this matter so that we can understand what are the advantages and disadvantages of such an approach for both visitors and museum and also how willing are people to embrace this approach instead of having museum-provided devices to use during their visit.

Nowadays, it is common for museums to provide the required devices for visitors to use during their visit (Like for example audio players for audio tours, tablets for video playback or QR Code reading, etc.) but this poses, for both museums and visitors, some disadvantages when compared to the use of the visitors own personal devices. For museums, these disadvantages are mainly related to the maintenance costs of the devices (battery charging, repairing or, worst case scenario, completely replacing the device itself as well as updating the devices to newer models) since these will be used extensively

[1] This was chosen in comparison to tangible interactions that had a earpiece attached which covered only one hear, making it, in our perspective, a choice that does not represent a major reason for preference over this interaction in other contexts where this problem would not exist.

and, consequently, suffer from extensive wear. On their end, visitors are exposed to devices they do not know (different OS, same OS but different version, etc.) and that have been used by other people which raises hygiene questions.

Regarding the advantages and starting with museums, the fact that people would bring in the devices they own in order to interact with the exhibit would mean museums would not have the responsibility of maintaining, handing out and gathering devices at the entrance and exit respectively which, in turn, would equate into severe cost savings. Visitors on their end would be able to use their own devices which they are already familiarized with, erasing problems regarding hygiene and use of the device itself.

Even with all of the aforementioned advantages, the study found that there are still several barriers to overcome before this practice becomes a viable way for users to enjoy an exhibit with the use of their devices. In fact, one of the barriers is exactly that half of the visitors that were happy to use a phone when visiting the museum also expected it to provide the devices. Furthermore, when we take into consideration that, of the people that were happy to use the phone during the visit, only 20% of them had downloaded and used a museum app before we begin to understand one of the claims this study makes that states that ”providing an app does not guarantee visitors will use it and museums may need to hand-out devices if they want to reach out to a larger number of visitors.”. This study also inquired visitors who did not want to download an app the reason behind their choice, only to find that the top two reasons were ”I don’t want to spend time on my phone, I’m here to visit” and ”I don’t want extra apps on my phone” with percentages of 55% and 45% respectively.

In the end, we can see that phones are an important device to include in a museum visit for people that enjoy interacting with an exhibit through this device but, as we could observe throughout this section, there are still several challenges to overcome, especially with regards to the BYOD approach. Regarding the design and development of a mobile app, extra thought must be given to this since people might not be willing to download such an app just for the purpose of visiting. Additionally, there is also the issue of mobile devices heterogeneity which makes it hard for museums to make use of certain technologies (NFC, QR Code, 5G, etc.) that some or most people might still not have access to (Old models with no support for those technologies).

2.2.2.C The Tangibles

An alternative/complement to the use of phones are tangible interactions. Tangible interactions have proven to be a type of interaction that, when in the context of a museum, seem to be ”highly evocative and able to engage visitors in a deeper and more intense way” [13] and do not have as many barriers to their use as mobile devices have. Within tangible interactions, this study considered two sub-types, historically accurate smart replicas and simple Smart Cards. In contrast to the fact mentioned in sec-

tion 2.2.2.A, where the phone was the most disliked type of interaction of the three, here we find that tangibles are the most preferred interaction type with an overall percentage of preference of 60%. The reasons behind this were **simplicity and ease of use** and the fact that this type of interaction was **playful** and **physically engaging**. On the other hand, visitors pointed out one particular reason for disliking tangibles which is related to the way the interaction was implemented and therefor cannot be used as an example for a flaw that generally this type of interaction presents. What we can state is that, one of the major challenges of deploying tangible interactions, is their requirements space wise and their need to be tailored to fit the exhibit as an integral part of it and not just an add-on.

One of the most interesting findings of this study was the lack of importance attributed to the aesthetic aspect of the replicas. As previously mentioned, this study employed two types of tangibles, **smart replicas** that valued the historical accuracy and aesthetics of the object and **smart cards** that worked exactly the same as the smart replicas but were not concerned with the aesthetics of the piece. This raises the question of whether is it worth for museums to invest in high polished, historically accurate, replicas for visitors to use or if simplicity and practicality should be more of concern.

2.2.2.D Ants and Fishes

The last topic we will analyze to conclude our analysis of the study by Petrelli and O'Brien is the association between preferences for an interaction type and the association of that preference to the visitor's visiting style/behavior. Researchers found that visitors displayed mainly two behavior types that fit the categories of Fish and Ant purposed by Veron and Lavasseur's [44]. People that displayed a Fish behavior moved around a lot throughout the museum, generally preferring to have an overview of the exhibit rather than getting close to the pieces, interacting with them and observe the details. Contrarily, people that displayed an Ant behavior spent time appreciating each piece, observing the details and reading the information that was provided regarding it. It was found that those who preferred the phone as a way to interact with the exhibit were visitors that displayed a Fish behavior while those who preferred tangibles displayed an Ant behavior.

Researchers also tried to see if the interaction played an important role in the visiting behavior of the person but found that, no matter the interaction that the person uses, the behavior remains unchanged. This allows us to conclude that one type of interaction might not achieve the objectives that the museum wants for its visitors since they might not have a behavior that would favor the use of that interaction. Instead, museums should aim at providing multiple choices, making several types of interactions available that will fit diverse visiting behaviors so that people can take advantage of them and enjoy the visit in the way they tend to enjoy more. Furthermore, each type of interaction has its own advantages and disadvantages and so diversifying them will allow museums to tackle the disadvantages of some interactions with the advantages of others.

2.2.3 Context Aware Interactions

The last interaction type we considered relevant for our work are Context Aware Interactions. Context Aware Interactions are, similarly to Tangible Interactions, a type that encompasses interactions that are triggered via a context variable or that make use of context to be played/used. To understand the possibilities and advantages/disadvantages that this interaction type can provide, we analyzed two papers that tested the use of context-aware systems in museum environments to get a perception of the results one can expect when deploying such a type of interaction in a museum. The first and most relevant study for our work [45], implemented a context-aware knowledge map (CAKM) that made use of several interaction types that we have analyzed previously in this work. In this research, students used a system that, through the use of RFID cards/readers (Tangibles) and QR Code technology (Mobile Devices) to perform the situation awareness (context) component, enabled them to acquire knowledge about several plants in the botanical museum by using the RFID readers that their mobile devices possessed to scan RFID tags associated to a certain plant and then obtain the information related to that plant on their mobile devices.

This system showed promising results with users reporting shorter learning times and higher correct learning rates which, in turn, lead us to the hypothesis that deploying such a system in a museum may achieve the learning objectives that museums have for their visitors. In fact, this hypothesis is on par with the claims of the individuals that used the system, saying that they believe it helped them acquiring knowledge about the plants easily. Additionally, users also believed the system enhanced both their motivation to learn and learning effectiveness and showed intentions of using it in the future. These results are consistent with those of other studies that concluded that people's attitude towards these systems are positive which, once again, shows potential for this system to be used in a museum to enhance user experience, motivate people to return and re-use the system and to also contribute to other studies that may try to better understand what are the effects in people's learning.

Similarly to the previous one, this study [46] also relied on location to implement their solution. They did this by leveraging the use of a BLE infrastructure installed in the museum where the system was deployed, that would provide the localization information to a wearable device that visitors carried during their visit. This device had image recognition capabilities that, alongside the localization information, would provide visitors with information regarding pieces of art they were contemplating. One feature of this work we intend to include in our solution, is the ability to communicate information to users outside of the museum. This extends the reach of the museum by erasing its physical barriers and providing outside users relevant information (Current number of visitors, temperature, noise levels, etc.). This is achieved through the use of social media and cloud technologies to share multimedia content and provide useful information (Length of queues in specific areas of the museum, most admired artworks, etc.) to users outside of the museum respectively.

In conclusion, context aware interactions/systems can make use of important context variables to not only deliver content to visitors but also to aid museum in the monitoring of their spaces. They have proved, as seen by the two previous studies, to have potential in terms of providing an educational and fun experience to users and, of all of the interaction types we have and will analyze, context aware interactions stand out as the ones with the most potential to achieve one of the inherent objectives of our work which is to turn the museum into a smart space.

2.2.4 Virtual Reality and BCIs

Lastly, we want to analyze other types of interactions that can be created using technologies that are gaining popularity and becoming more mature and accessible with time, especially VR and Brain Computer Interface (BCI). The studies that feature applications of either technologies, especially BCI, in a museum context are scarce when compared to studies focused on the use of interactions such as those mentioned previously in this section but, the potential that these technologies have is vast and some of the few studies that use them show exactly that. The first research [22] concerns the use of a BCI in order to detect people's implicit engagement for interactive museums. This way the system can provide real-time suggestions in order to personalize user's experience so as to create a more enjoyable visit by detecting which pieces in exhibit does the user seem to be engaging with more, tailoring the visit in real time and creating a more personal and hence enjoyable experience.

Regarding Virtual Reality, VR is becoming ever more present in people's lives due to its increasing accessibility in terms of price (Cheapest VR equipment in 2019 was 249€ [47]) and ease of use. In fact, it's expected that hardware and software related to VR reaches a world wide market size of 5.1 billion U.S. dollars [48] and other forecasts indicate even bigger numbers [49]. Throughout section 2.1 we were able to see that some museums are already employing the use of VR with the purpose of creating a virtual replica of their own spaces. This is just one of the many possible applications that VR has but there are some barriers to its proper adoption in a museum context, mainly due to the fact that it's a type of technology that requires some space and, if VR is used for more than just visualization of content, it will also require the setup of several pieces of equipment so that people can be able to also interact with the content they are watching. One study [50] points out several problems that VR can address like, for example, the possibility for people to be ”transported” to another period in time and have a deeper perception of reality in that time. VR can also allow people to experiment with dangerous or sensitive objects without actually running the risks associated to them or their incorrect manipulation. These two reasons, and others, are also part of the reason why VR can ”offer great advantages for learning”, aiding museums in the achievement of this educational aspect that a visit should always have.

We have seen throughout this section the advantages and disadvantages of some of the most predominant interaction types that are currently being used in museums with the intended purpose of en-

hancing visitor's experience by creating a more interactive, enjoyable and overall memorable experience through the use of technology. Analyzing all of this will allow us to develop a support infrastructure that will have to be prepared to handle these types of interactions which will also allow us to develop an Escape The Room game whose composition shall reflect an extensive use of these types of interactions so we can benefit from all of the advantages that each provides.

2.3 Technologies

Following the previous chapter, the arising question is, "If one is to design a support infrastructure for an Escape The Room game and the most common interactions are the ones seen above, what kind of technologies do these interactions require that, consequently, the infrastructure needs to support?". Given this question we decided to investigate what are the main technologies that several interactions in section 2.2 use so that, when designing the infrastructure, they can be supported. Additionally, it is also convenient to analyze other technologies that will contribute to the transformation of the museum into a smarter space. We begin this analysis by discussing the applications, advantages and disadvantages of Bluetooth Low Energy (BLE) followed by Radio Frequency Identification (RFID)/Near Field Communication (NFC) and lastly Quick Response (QR) Code technologies.

2.3.1 Bluetooth Low Energy

BLE is one of the main technologies used in several studies that we have analyzed and used as inspiration. One of its major applications is indoor localization [24–26, 51] where BLE is used to acquire the location of visitors or items that possess a BLE compatible device. This application is one that can be used to provide location information to context-awareness interactions or simply to understand where visitors are located in order to give a better understanding of which pieces in the museum are receiving more/less attention and also to be able to tell people outside of the museum, for example, the number of visitors currently visiting. These pieces of information are relevant for several purposes besides these but, as demonstrated in another work [23] performed in the Computation Museum at Instituto Superior Técnico, the use of a BLE infrastructure to provide localization information is not viable as the results from this work show that an accurate location of a user/device cannot be performed in the space that is available in our museum.

Even though BLE cannot be used for one of its most popular applications, it is worth noting that the applications BLE has, as well as the market adoption this technology is predicted to achieve, are more than enough reasons for an infrastructure like ours to support it. Since "BLE easily integrates into classic Bluetooth circuitry" [52] it is expected that a great majority of smartphones in the future shall support BLE, increasing the possibilities that this device will present as an instrument to interact with the

Technical Specification	Classic Bluetooth	Bluetooth Low Energy (BLE)
Radio Frequency	2.4GHz	2.4GHz
Distance/Range (Meters)	100	100 – 500
Over The Air Rate (OTA Rate)	1 – 3 Mbit/s	125Kbit/s - 2 Mbit/s
Application Throughput	0.7-2.1 Mbit/s	0.27-1.37 Mbit/s
Active Slaves	7	Implementation Dependent
Security	56/128 bit and Application Layer User Defined	128 bit AES in CCM mode and Application Layer User Defined
Robustness	Adaptive Fast Frequency Hopping, FEC, Fast ACK	Adaptive Frequency Hopping, Lazy Acknowledgement
Latency (Non-Connected-State)	(Typically) 100 ms	6 ms
Transmission Time	0.625 ms	3 ms
Voice Capable	Yes	No
Network Topology	Scatternet	Scatternet
Power Consumption (Watt)	1	0.01 – 0.50 (Use Case Dependent)
Peak Current Consumption	<30 mA	<15 mA

Figure 2.5: Comparison between Classic Bluetooth (Versions 1.0-3.0) and Bluetooth Low Energy (Versions 4.0-5.0)

museum (sensors, access control, ticketing, etc.) and its exhibits. In contrast, one might question the use of BLE instead of classical Bluetooth since the latter is already present in the majority of devices (100% of the shipped mobile devices in 2018 like smartphones, tablets and laptops were predicted to have integrated Bluetooth connectivity [53]) and so, in order to answer this question, we must compare the characteristics of these technologies(fig. 2.5) against the objectives we set out for this work so as to further understand the importance of supporting BLE.

By taking a closer look at fig. 2.5, we see two features of BLE that stand out as major advantages for our solution when compared to Classic Bluetooth which are, power consumption and range. Power consumption is important due to the the fact that some devices (especially sensors) will not be connected via cable to the Raspberry Pi's and, instead, will have to be battery powered. This, in turn, is one disadvantage since these batteries will require charging/swapping periodically and so, in order to try and mitigate this issue, the battery powered device must consume the least amount of energy possible and this is where BLE excels when compared to traditional Bluetooth. Range is another feature where BLE excels and contributes to a reduction in the number of devices required to provide full coverage of a museum since BLE provides 5x bigger ranges than classic Bluetooth. To put this in perspective, if we were to deploy our system in the Louvre, which is one of the biggest art museums area wise (72,735 square meters) [54], and had to install a Bluetooth infrastructure that needed to provide full coverage of the museum, we would require 146 BLE devices instead of 728 traditional Bluetooth devices[2].

[2]These results assume an effective coverage of 500 and 100 square meters for BLE and Classic Bluetooth respectively. Due to interference's caused by people, structures and other factors, expected results would be different

2.3.2 Radio Frequency Identification/Near Field Communication

The importance of RFID for our work and for the general topic of smart museums and gamified experiences is related to the diverse applications this technology has. In fact, we have seen in some of the analyzed studies, some applications of RFID. In section 2.2.2.C, RFID was used to create the Smart Replicas people would use to interact with the exhibit. In section 2.2.3 RFID was used to provide context awareness when visitors scanned tags to acquire knowledge about plants they were observing. Even though these examples are centered around the objective of enhancing museum experience, this technology has the potential to be used for purposes that serve not only the visitors interests but also the museum (ticketing purposes since an RFID tag can be used as a ticket, allowing museums to control how many people are currently in the museum, access control purposes, among many others).

Allied to this versatility, RFID is becoming ever more present in people's everyday lives (especially at the time of writing due to the COVID-19 pandemic), yet, it is not RFID in the most common of cases (contact-less payments) but rather a subset of it called NFC. NFC shares a very similar way of operation with RFID which in turn allows us to hypothesise that, as a technology to adopt in museums, either NFC or RFID would be very well received since people are already familiarized with them, making them exempt of any tutorial or guidance by museum staff to be used correctly. However, at this point, it is useful for us to understand if these technologies will share the museum or if there is actually only need for one of them. To do this we must first understand what sets NFC and RFID apart, what are the most appropriate applications for each, and the advantages/drawbacks of these technologies.

The major factor that marks the differences between RFID and NFC is the fact that RFID is centered around items/objects and NFC, on the other hand, is centered around users/people which in turn sets these technologies apart in terms of the applications and technical characteristics. Starting with RFID, it is an improvement over typical bar codes since the former does not require line of sight to the object(tag) that is reading, has an increased range compared to the latter and can be read in batches. On the other hand, NFC is an improvement over QR codes as the former, similarly to RFID, does not require line of sight and has increased security. Regarding equipment, RFID usually requires 3 elements (tag, antenna and reader) while with NFC the reader can also simultaneously act as a tag, greatly reducing the amount of equipment that has to be deployed, making NFC a least invasive approach when compared to RFID since a visitors smartphone can be used as reader.

Another distinctive feature about these technologies is their range of operation where RFID stands out as the one with the biggest range out of the two. Depending on the frequency of the radio waves, RFID can go from 0-10cm (Low Frequency (LF)) to up to 100m (Ultra High Frequency (UHF)) while NFC can only read tags in a range of 0 to 10cm, a characteristic that makes NFC more secure than RFID. Taking all of the previous into consideration we can now see the most common applications of both technologies and determine whether or not if both have a purpose in the museum or if one is enough.

Starting with RFID, it is commonly used for attendee tracking, access control and item location. This technology can be employed, in the context of a museum, not only as an interaction, as seen previously, but also as a way for staff to control how many visitors are currently visiting, replacing paper tickets by RFID tags. Differently, NFC is mostly used in contact-less payments, a use that is becoming popular with mobile payment services (Google Wallet, Apple Pay, etc.) but can also be used to transfer information between devices, a feature that can be put to use in the museum so that, for example, visitors, through the use of their NFC enabled smartphones, can acquire content on their devices.

The previous examples are enough for us to conclude that each of these technologies have a distinct purpose in the museum, with RFID being used not only as an interaction but also for ticketing purposes and access control and NFC being used to deliver content to visitor's mobile devices, making these devices an integral part of the exhibit.

2.3.3 Quick Response Code

The last technology we would like to address are QR Codes. We have previously mentioned in section 2.3.2 that NFC is an improvement over QR Codes since the latter is more capable in the sense that does not require neither line of sight or good lighting to operate and, provides increased security so why is this technology relevant when there is a better one that can be used for the same purpose as QR Codes? In 2017 there were over 2 billion NFC-enabled devices [55] and of these two billion we do not know their distribution[3] but, if we were to assume that one quarter of the worlds population had access to an NFC-enabled mobile device, that would still imply that museums would be facing the possibility of only one out of four visitors would have a device that would allow them to interact with NFC interaction-s/devices. This problem is expected to disappear in time since the size of the NFC market worldwide is expected to reach 47.3 billion dollars [56] but, until then, QR Codes are a viable alternative/complement to the use of NFC.

One of the reasons that justify the relevance of QR Codes nowadays, is the popularity that QR codes have gotten in recent times, especially due to the COVID 19 pandemic. Observing the available data, we can see that in the United Kingdom (UK) and United States (US) alone, we have over 60% of people using QR codes [57] and, if we consider other statistics [58] that show that QR code reach and number of interactions have increased over 20%, we can say that this is a technology that, even though it's becoming outdated, still has a lot of popularity amongst people and institutions alike (for example, starting in 2022, invoices in Portugal must have QR codes). To give a more contextual piece of data that justifies our claim that QR codes are a valuable technology to have in a museum, a study [59] that inquired 403 cultural institutions in Italy shows that over 70% of these are already providing/intend to

[3]There are people with more than one device which allows us to assume that the fact there are two billion devices with NFC worldwide, that does not imply that there is 2 billion people with an NFC-enabled device

provide QR codes to be used in their spaces. This is enough to show that QR codes are still growing in usage and popularity and cultural institutions in particular are also intending to adopt this technology to use in their spaces.

Furthermore, there are also the advantages that QR Codes possess when compared to NFC, namely cost, visibility and ease of recognition by people as well as compatibility across devices. We mentioned earlier in section 2.3.2 that museums faced a risk of having only a quarter of its visitors having an NFC enabled device that would allow them to interact with other NFC devices made available by the museum. QR codes do not suffer from this issue since the only feature a device must possess in order to scan a QR code is a camera and seeing that in 2012 alone, over 80% of all phones possessed a camera [60], we can safely assume that nowadays over 4 out of 5 visitors will be able to use their device to scan a QR code.

2.4 Escape The Room

To develop an infrastructure that has the purpose of supporting an Escape The Room game, one must first understand this game, how it is played, the people who play it and how can it aid museums in their mission teaching people history whilst motivating them to return.

2.4.1 Definition

Before analyzing the details around Escape The Room games, we need to define what an Escape The Room is in the context of our work. To do this, we analyzed several studies [61–65], each of which had their own definition that was either based on other definitions or was completely independent, and defined what, for our work, was the most appropriate definition which is, an **Escape the Room is a live-action, team-based game where the players are literally or figuratively locked in a physical space and, through the discovery of clues and resolution of puzzles, that may, or may not, depend of those clues to be solved, the players must attempt to accomplish a specific goal, typically escaping the room, within a certain time limit**. With this definition in mind, there are still questions left unanswered regarding the specifics of the game, and these go from ”How many members does a team have and what is the minimum and maximum amount of members?”, ”How long should the Escape The Room last?”, among many others that arise with the use of a game like this, especially in the context of a museum. To answer these questions, we resorted to a survey [65] that provided several insights on Escape The Room facilities and helped us gain some knowledge on how should we proceed regarding the development of our own Escape The Room.

2.4.2 The Players

As previously mentioned, this is a team-based game and so it is important that, when designing an infrastructure and an Escape The Room game, that we understand some of the most important aspects regarding what can be considered the central element of this game, the players. The first aspect is the demographics of the people that usually play this game. Even though this is a changing trend, the games industry is becoming more balanced in terms of the predominant gender that actually plays games. In the US, one of the biggest gaming markets in the world, we observed, in the year of 2020, that a bigger balance between genders is being achieved since it was reported that 59% of players were male and 41% female, indicating that gaming and games in general are becoming increasingly more attractive for people, independent of gender. Escape The Room are one example of games where there is not a predominant gender, in fact, data [65] shows that most groups(71%) taking part into this type of game are composed of mixed genders while only 14% and 15% are groups composed of only females and only males respectively. The previous study also analyzed in more detail these percentages and reached a very favorable conclusion when it comes to using this game in the context of a museum, it observed that, of the inquired facilities, they reported ”About 37% of groups are groups of players over 21, about 14% of players are families with parents and children, while 19% are groups of players under 21” which in turn shows that this is a game that appeals to people of different age groups.

Even though the study by Nicholson does not analyze the relation between the size of the facilities where an Escape The Room takes place and the size of the teams, we can safely assume that, bigger facilities provide better conditions for bigger teams to play while those where space is more limited have to provide an experience for smaller teams. On the other hand, the study did analyze team sizes by continents and for our particular case, Europe, it discovered that we possessed the smallest teams, averaging 3.98 members per team with the maximum reported number of players in the same team being 7. It is important to consider these factors when developing such a game since a team with too few members may prove ineffective given the amount of skills that are usually required to win [64] but, contrarily, having teams with too many elements may negatively affect the experience of the players if, for example, the available space is too small or if the average size of groups of people that come in together to play are not enough to fill a team (grouping random people can ruin the experience for some players). If we take these issues and put them in the context of a museum we have questions like ”How much space is available for the game to take place?”, ”Are the players near/handling pieces in exhibition or expensive replicas of them?” and ”What is the average size of the groups that come in to visit the museum?”. All of the previous questions are important in order to adapt the Escape The Room to the nature of each museum since we cannot expect museums to adapt themselves to the game.

2.4.3 Puzzles

One of the last important aspects we must analyse about Escape The Room games are the puzzles. The puzzles are a crucial element since they will constitute the main challenge component in the game loop. When designing these puzzles, several aspects have to be taken into consideration so that the player experience isn't ruined. Difficulty, for example, is one of the hardest aspects to balance when designing an Escape the Room puzzle since making it too easy to solve will lead the players to a state of boredom while, on the opposite, making it too hard, will lead them to a state of frustration. These issues, alongside the types of puzzles, their organization and the mechanisms that we need to have in place for when players aren't capable of progressing, will be analyzed in detail throughout this section to understand what is the best approach when developing both the game and the infrastructure.

Starting with the types of puzzles featured in Escape The Room games, this is a topic that brings some relevance to the observation we made previously regarding the importance of diversity of interactions. The same way that having several interaction types may appeal to people with different visiting styles, the diversity of puzzles also contributes to the enjoyment of people with different interests regarding the types of puzzles they like to solve. On this topic, the study by Nicholson shows that, depending on the continent, there is a predominant puzzle type in Escape The Room game facilities and also shows, globally, what are the most and least used puzzle types. This provides some assistance when designing the game since if it features puzzles that are not common in that continent or not common at all it will contribute to the uniqueness and possibly difficulty of the game.

2.4.3.A Puzzle Organization

As we have mentioned, an Escape The Room provides a series of puzzles and challenges that players must solve in order to progress and win. The organization of these puzzles, from a game and infrastructure standpoint, is a topic to have into consideration because it can greatly affect player experience and the development of the infrastructure for reasons which we will analyse throughout this section.

When it comes to puzzle organization, we have two different ways puzzles can be presented to the players, individually or sequentially. The former is when "each puzzle feeds directly into a large meta-puzzle" and the latter is when the players must solve one puzzle to get access to what they require to solve the next puzzle. When it comes to the most common methods of organization, the sequential and path-based methods, that belong to the sequentially category, are the ones most observed in Escape The Room facilities with the open method, belonging to the individually category, being the least popular.

Starting with the path-based method, here teams are presented with different paths of puzzles simultaneously and can choose which one they will tackle first. This structure has the advantage of providing different team members the possibility of working simultaneously on different puzzle paths and also allows the game designer to incrementally increase the difficulty of puzzles in each path. The sequential

structure also provides the advantage of incrementally increasing the difficulty of puzzles along the path but it is aimed at smaller rooms or when the focus of the puzzles is having the entire team working on them instead of individual members. Additionally, there are also hybrid models that combine the aforementioned methods to create a different and more complex experience for the players.

We can now understand why it is important for an infrastructure standpoint to consider these different organization methods. We are not creating an infrastructure for a specific museum or a specific game, we are creating it to be able to fit any museum and support different Escape The Room designs and for that the infrastructure must provide the museum and game designers the ability to create games and organize them as they deem fit. This also reinforces the importance of creating the infrastructure and the game itself as modular as possible to allow for these types of reorganizations to happen without that implying major changes to the way the infrastructure is built or preventing people from creating different experiences with the same set of interactions.

2.4.3.B Hint Mechanism

The last topic we should analyse concerns the hint mechanism Escape The Room games usually provide to allow players to request help in order to further progress through the game. The survey by Nicholson shows that methods for hint distribution vary a lot, with 23% of facilities not allowing players to request hints, instead they would be provided when the game master determined, 42% allowing players to request hints when they need and another 23% also allowing players to request hints when they need but have a limited number of requests, sometimes even suffering penalties for each hint requested. In the end, only 3% of the inquired facilities would provide no help to players.

Each of the previous approaches have their advantages and disadvantages but the main conclusion we should draw from this analysis, similar to the conclusion we drew regarding the puzzle organization, is that giving museums the ability to choose which hint mechanism they should provide, if any, is important and that implies, again, that, when designing the infrastructure, this is taken into consideration.

3

The Solution - Peddy Room System

Contents

With the previous chapter, we understood the diversity of issues, interactions and technologies that are commonly employed in the creation of an interactive museum experience. Additionally, in section 2.4, we analyzed all of the requirements and problems with the use of an Escape The Room, particularly in a museum context, which is, not only one of the games that our infrastructure will support, but it is also the culmination of the several types of interactions and technologies that we analyzed, all in a single game. This acquired knowledge will, throughout this chapter, be used to guide and justify all of the decisions that were made design-wise with regards to the architecture of the system, the technologies and devices that were chosen to support the infrastructure and the way all of these will be used to implement the escape the room.

3.1 Architecture Design Requirements

Before detailing the several requirements that our infrastructure has to satisfy, we must first reiterate the main objective this work is trying to achieve which is to create an IoT support infrastructure to be deployed in a museum that will allow us to instrument the museum, support the execution of interactive experiences and the creation of a smart environment. This infrastructure must be able to adapt to different configurations and topologies of museums while at the same time being as least intrusive as possible so that the visitor experience remains unaffected, in a negative way, and the acceptability by museum curators of the solution is, in turn, as high as possible. Alongside these requirements, there is also the one of affordability which cannot be compromised at the expense of the others, since developing a good infrastructure that is too expensive to the point where price becomes a considerable barrier for adoption, then, ultimately, our solution could be deemed a failure.

We will begin by addressing the requirement of adaptability/scalability which dictates the ability that our infrastructure has to possess in order to be able to adapt to different museum topologies and properly scale without it negatively impacting performance. Museums are environments that are prone to relatively frequent changes since they accommodate new expositions and/or pieces to showcase and therefor changes to the topology of the museum are bound to occur. With this in mind, if our infrastructure is to properly cover different museums and adapt to the changes that each museum is prone to suffer over time, it must be developed with the ability to adapt itself to the different museum configurations and, on top of that, be able to scale properly if these changes imply an increase in demands from the software and hardware that is used.

The aforementioned requirement closely relates itself to another, Inter Connectivity, which states that the elements of our system must be connected to some degree between each other. This requirement is crucial for the achievement of the adaptability requirement since the ability of having some connection between the several machines deployed in the museum, allows us to make all of the adjustments that are

needed and then, via software, configure the system appropriately. Not only this, but given the objectives set out for this work, having connectivity between the different elements of the system will allow us to have more coverage of the museum area, independently of its configuration, and also give us access to any machine remotely, erasing the need for direct interaction with a certain element of the system in order to manage it. This, in itself, allows the system to have more freedom in terms of placement of the machines, and, therefor, will make the task of disguising said machines with the museum environment a much easier task since, for the majority of the anticipated use case scenarios, direct access to those machines won't be needed. Additionally, this also facilitates the task of blending the infrastructure with the museum environment in the sense that it reduces the amount of cables that would otherwise have to be routed throughout the museum if it weren't for wireless technologies like Wi-Fi and Bluetooth. All of the previous advantages of designing our infrastructure so that it complies with the connectivity requirement are crucial for the implementation of a solution that can easily be integrated into a museum and managed by the corresponding staff, consequently increasing the chances for adoption of a solution like ours.

Having mentioned it superficially in the above paragraph, another major requirement for this infrastructure is discreetness, which is the ability for our solution to blend in with the existing museum environment without having it ruin visitor experience and without requiring major changes to the already existing museum infrastructure. A museum is an experience that revolves around several contexts such as the personal, the social and, also, the physical one. The physical context is the one where this requirement acts the most, and its importance can be associated with the importance of this context itself, which is discussed and analyzed in some research articles [66, 67] that make it clear that this dimension of a museum visit plays an important role in the overall experience of visitors. Having this into consideration, when designing our infrastructure, extra deliberation must be had in the choosing of elements that will constitute our infrastructure, and the relations between them, so as to make our solution the least intrusive as possible.

We have previously mentioned in section 2.1 that museums nowadays are taking efforts to integrate technology in their exhibits so that they can connect with younger generations and therefor attract them to visit. We also observed some of the current technologies that are being frequently employed for the creation of technology based experiences in museums and saw others that are the focus of recent studies but due to constraints of several natures haven't seen a great adoption by museum curators and have only been subject of some research studies that tried to understand the effects and use cases in a museum scenario of these technologies. Being mindful of this, we can safely assume that, similarly to the most frequently used technologies by museums nowadays, in the future, other technologies will also be part of the museum environment and can even replace some of the current ones being employed. This replacement of old/current technologies or even the addition of newer ones to the museum environ-

ment implies that the infrastructure must be able to adapt to these changes and must be prepared for this addition and replacement of components. This leads us to determine two additional requirements of our solution which are modularity (to easily replace a component for another without considerable effort being required) and extensibility (which allows us to add components to the already existing infrastructure). These requirements are also crucial when considering the interactive experiences (Escape The Room and Peddy Papper games) that our infrastructure will support since these will also be developed as modular and extensible as possible so as to allow changes and maintenance without making these unavailable for the visitors.

Just as importantly, there is also the requirement of affordability which is often a great barrier for adoption of solutions like ours. Developing a system that can fulfill all of the requirements and objectives that we have set out for this work can be a task that involves expensive equipment and can lead the overall cost of deploying a solution like ours to become very high. This can become a severe barrier for adoption by museums and therefor hinder our solution as inadequate since the entry cost is not acceptable. With this in mind, we will try to achieve all of the goals set out for our work using relatively affordable hardware (when such is possible) to diminish as much as possible the costs of adoption of our system as well as the costs of maintenance when something breaks and needs replacement.

To conclude, we have now seen all of the major requirements that our solution will have to comply with, which can be briefly described as:

- **Scalability –** The ability for our infrastructure to adapt itself to different museum topologies and grow without negatively impacting performance;

- **Inter Connectivity –** The ability for the elements of our infrastructure to organize and connect themselves via network;

- **Discreetness –** The ability for our infrastructure to perform its duties while blending in with the existing museum infrastructure;

- **Modularity –** The ability to separate our infrastructure into modules that can work independently of each other and easily exchanged by other modules;

- **Extensibility –** The ability to extend our infrastructure with newer functionalities and devices without it impairing existing system functionalities;

- **Affordability –** Making the infrastructure as affordable as possible with regards to the chosen hardware;

3.2 System Architecture

When designing the architecture of our system, we determined that the most logical choice regarding the architectural pattern of our infrastructure would be the Primary-Secondary pattern. In this pattern, a Primary process is responsible for, not only, the coordination of the several Secondary processes but also for the distribution of work throughout them. We established that our secondaries would be able to work as standalone units, gathering not only environmental data but also allowing the execution of interactive experiences and providing visitors with interactive elements that they can enjoy throughout their visit. When framing this in the context of the escape the room game, this will allow us to, by connecting to each of the required secondaries, provide a game that can span across multiple rooms within the museum and allow a great degree of diversity when selecting the interactions that will partake in that same iteration.

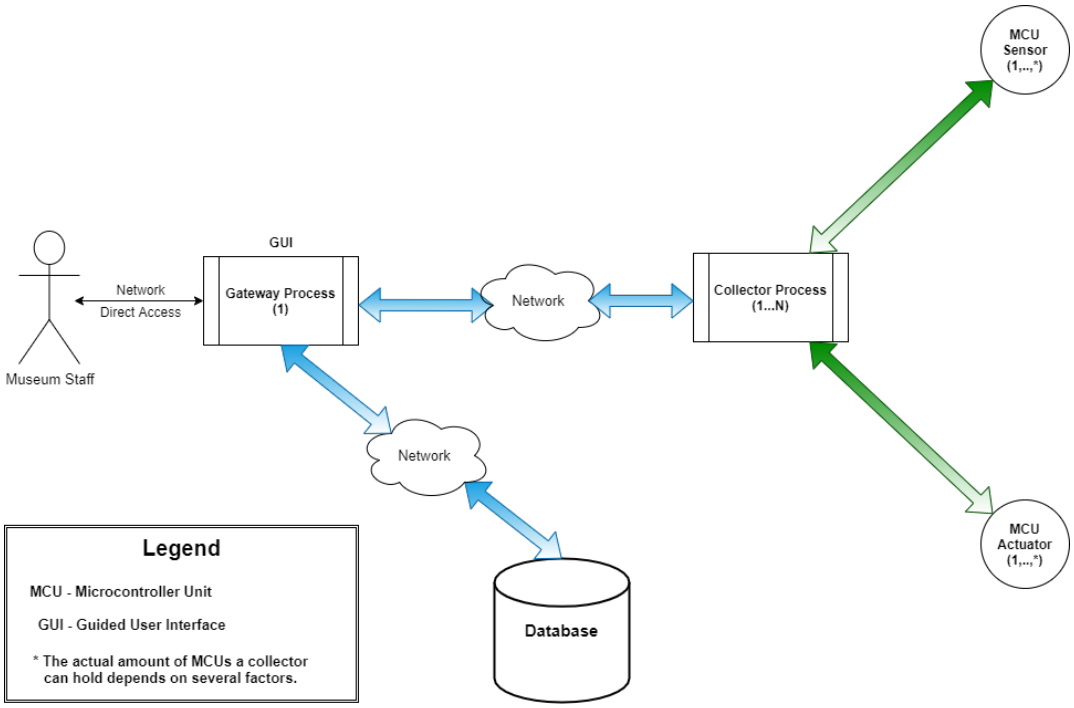

Figure 3.1: Simplified architecture of the infrastructure depicting its integral parts and relations

3.2.1 Gateway Process

By examining fig. 3.2, we can immediately distinguish the 4 layers that constitute our gateway process, namely the web, service, data access and communications layer. Besides this layered division, we can also observe the design pattern that this process is implementing, which is the Model-View-Controller (MVC) pattern.

With regards to the aforementioned design pattern, we will start by explaining the purpose of the web

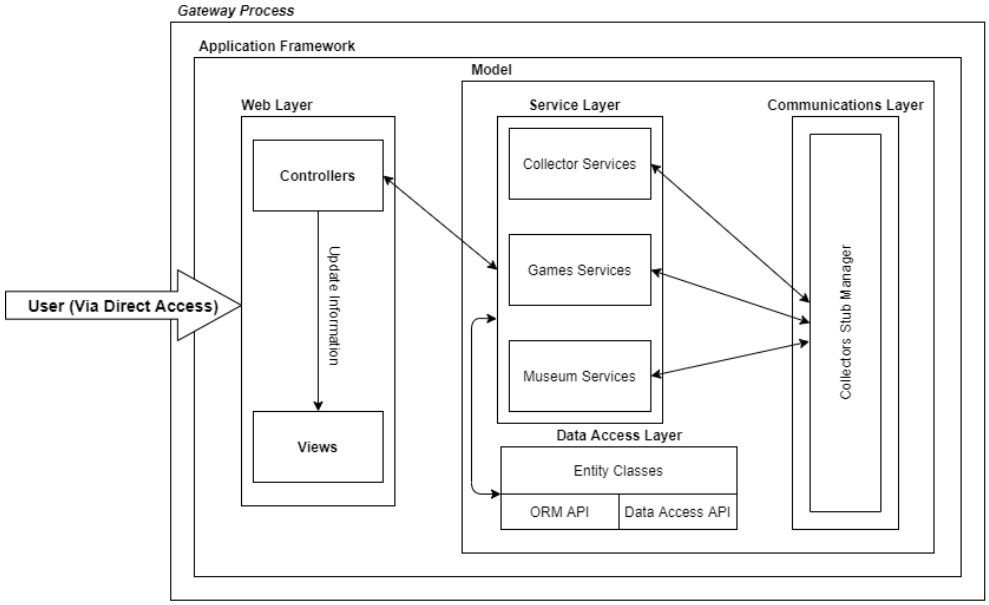

Figure 3.2: Master Pi architecture with all of its components and relations between them.

layer (which contains the views and controllers). As its been previously stated, this work was developed with the intent of being deployed in a museum where the staff will make use of the infrastructure to enhance visitors experience and manage all of its elements. For these purposes and due to the fact that the degree of technical dexterity of the staff is unknown, a Graphical User Interface (GUI) is required to facilitate the use of the infrastructure, otherwise, the technical skills required to use it would become a barrier for adoption. Even though the creation of a GUI is not the focus of this work, a simple one has been developed as a Proof of Concept (PoC) that can exemplify how the infrastructure is operated.

The model is where all of the application logic is contained, and each layer, as well as each module inside them, is responsible for different parts of this logic. We will begin by explaining the modules inside the service layer which are responsible for the main functions of the gateway process and, afterwards, we'll analyze the communications and data access layers and see their importance in the context of our application.

3.2.1.A Collector Services

Starting with the collector services, this module is the one responsible for the management of all the collector processes that will be running throughout the museum. Each collector is suppose to run in a single machine that will have several devices connected to it that will then be used to perform all of the sensing functions as well as provide the interactive experiences to the visitors. The most basic task this module is responsible for is providing the required mechanisms to establish a connection between the gateway and the several collectors. Once this is performed, it is also its responsibility to allow the user to

manage the collector processes by providing access to their management page that can only be access either directly or by remote connection via the gateway.

Additionally, it is also this module that keeps track of the state of each collector by periodically sending messages to determine if everything is working accordingly. This way, the staff can keep track of any unexpected errors that occur in any of the collectors and thus proceed to assure that the delivery of the interactive experiences and sensing of the museum environment is not affected. The opposite also occurs in the sense that if there is an error in the collector that does not imply an halt to its execution, the collector process, through the pre-established connection, reports these unexpected errors to this module which then deals with them accordingly.

3.2.1.B Games Services

The games services is the one responsible for coordinating and managing the interactive experiences. This module is responsible for the basic functions of a game (starting, stopping and, when applicable, pausing) as well as keeping track of its progress. Furthermore it's also responsible for assuring that the execution of an iteration of a game goes without errors and, if any are to occur, to deal with them appropriately without necessarily implying an halt to the execution of the game.

3.2.1.C Museum Services

Lastly, the museum services module is responsible for all of the mechanisms regarding the acquisition of data through sensors that are scattered throughout the museum. As we have previously mentioned, the collectors are responsible for performing the sensing tasks and store the acquired values in a database in order to keep track of the changes throughout time. On the other hand there is also the need to check the values being reported by the several sensors in real time and organize these values by location to facilitate monitoring and that is where this module acts.

Regarding the two remaining layers, the data access and communications layer, we will not be going into detail since these layers work as support layers for the service layer and allow the latter to persist data in a database through the use of object–relational mapping (ORM) and data access API's (Data Access Layer) and communicate with the several collectors (Communications Layer) to perform the relevant system functions that require so.

3.2.2 Collector Process

The secondary process in our architectural pattern, the collector process, whose composition can be seen in fig. 3.3 also implements the MVC design pattern and shares some similarities regarding its layers to the gateway.

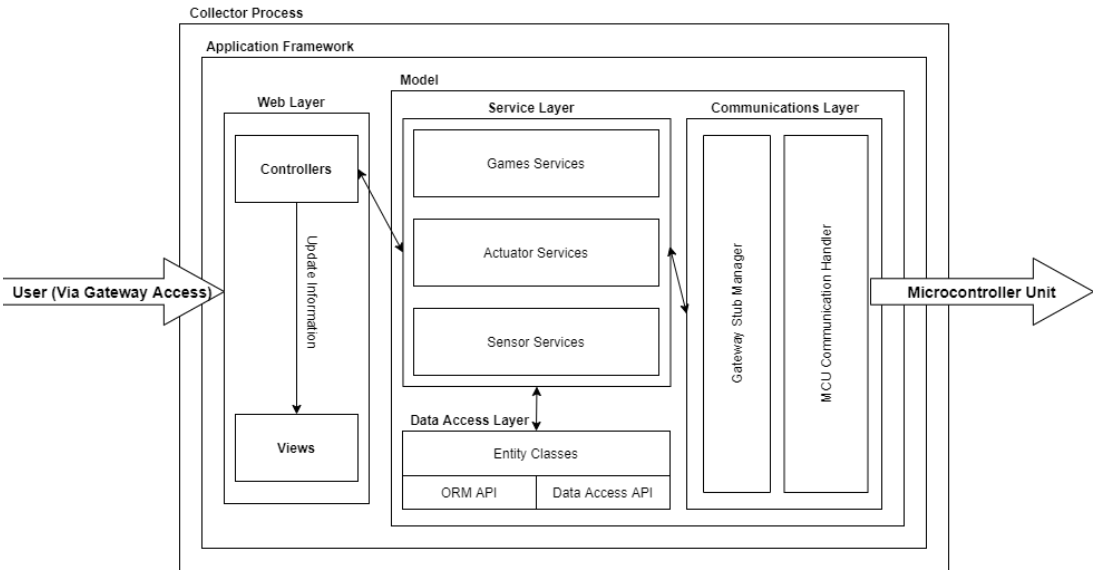

Figure 3.3: Interaction Pi architecture with all of its components and relations between them.

As with the gateway process, the collector also possesses an interface, contained in the web layer, that allows a user, either by direct access to the machine where this process is running or, via the gateway process, to manage the services that the collector provides.

We'll start by briefly explaining the games service which is an extension of the same service in the gateway. The reason for this statement is due to the fact that this service simply prepares the collector, and attached devices, for the execution of a game. The way this is done is that, after selecting the devices that will partake in the game, the gateway sends a request to the collectors, to which the selected devices are connected, and these, through this module, proceed to secure the devices to be used in that game instance. If anything fails it is reported back to the gateway, warning it of the error.

The actuator services is responsible for all the mechanisms that allow the collector process to manage each actuator (referred to as interaction from now on). These mechanisms allow a user to check information regarding each interaction that is connected to the collector and manage important parameters of it such as the baud rate of the port it is connected to, its schematics, etc... Managing an interaction may imply changes to the actual data in the MCU and to be able to achieve this, the actuator services module relies on the MCU communication handler to send formatted messages to the MCU, which then interprets them and sends back a response acknowledging the request. This response is then sent back to the actuator services module so that it can acknowledge the operation on its end and provide feedback to the user.

The sensors service, on the other hand, is responsible for collecting and storing (via the data access layer) the values that the sensors report back to the collector. Once again, there are operations that can only be performed by accessing the the software running in the MCU to which the sensors are connected

to, namely changes to the frequency of the sensors, and so this module also makes use of the MCU communication handler.

Now we can explain all of the logic behind the use of MCUs for the deployment of interactions and sensors. To do this, we must first begin to explain the consequences of not using MCUs for this effect.

With affordability in mind, there is the issue of the hardware that we can use without compromising on this requirement. In other words, the hardware that we will need to deploy to run the gateway and the several collectors has to be affordable. Consequently, its computational power will be very limited when compared to other, more expensive, alternatives.

Taking this into account, all of the available processing power that our hardware possesses should be allocated to running either the gateway or collector, and not concern itself with the logic related to the interactions or sensors. This is where the MCUs play a crucial part because it's their responsibility to run all of the software and hardware, in the case of tangible interactions, allowing for a clear separation of responsibilities. The hardware that is running the collector process is concerned with only computing intensive tasks while the MCU handles all of the controlling one which, in turn, allows real time feedback to the users since the processing power of the MCU is entirely dedicated to a single task. When required, the MCU communicates with the collector to perform something out of its capabilities (like for example, warning the gateway that an interaction has been solved).

3.2.3 Database

Lastly, we can now address the third major component of our infrastructure which is the database component. The importance of this component is related to the fact that we will have several services and experiences running in the museum and, since the inclusion of games and interactive elements in the context of a museum so as to enhance the visitors experience is a recent topic, which hasn't had enough studies in order obtain a clear conclusion on its actual effects on visitors experience, the database component will be the one responsible for persistently storing visitors feedback and improve the games accordingly. Similarly, but not as relevant as this data, it is also valuable to store information regarding the data acquired by the several sensors so as to, in the future, correlate this data with visitors behavior in the museum, time expended at each interest site, etc... This is not the concern of this work, but it is our concern to build and deploy the required elements to allow future works to leverage this infrastructure for the mentioned purposes.

3.3 Escape The Room Architecture

We can now explain the architecture of the Escape The Room which will leverage our infrastructure to determine if we were able to achieve the intended objectives. To understand how this game was

developed we must first understand what are the interactions that have been previously mentioned in this chapter, how they were built and what is their overall role.

3.3.1 Interactions

Firstly, and before detailing how the interactions were developed and deployed, we must first recall the several types of interactions discussed in section 2.2, which are serious games, tangibles and context aware interactions. We have also mentioned that it's important to try and achieve a variety of interaction types but saw that the benefits of tangibles, when in a museum context, are more valuable when considering that the museum is a place of education. An interaction, in the context of this work, can be described as a mini game, which is a smaller game that contains different gameplay elements than the Escape The Room and is more simplistic than the latter.

The interactions that we developed are mainly tangibles and, in some cases, a mixture of both tangible and digital (to allow contact with computer interfaces). The support hardware for these tangible interactions are Arduino Nano microcontrollers with a USB C port and 20 usable I/O pins (Two of the pins, specifically pins 1 and 0, cannot be used due to the communication between the MCU and the collector) that allow us to connect several sensors and actuators to build the interactions we'll see later in this document.

Now, given the definition of an Escape The Room game in section 2.4.1, we know that this game revolves around the discovery of clues and resolution of puzzles. Instead of designating them as puzzles, we designated our puzzles as interactions and developed twelve that together will form the Escape The Room game.

The development process of the interactions was a three stage process that started with the circuit design and development, followed by the programming of the MCU and lastly, once all of the functionality of the interactions was proven to be working and that the MCU possessed the required I/O to build the circuit, we then proceeded to 3D model the enclosures, one of which can be seen in fig. 3.4.

Regarding the developed interactions, they can be briefly described as:

1. **Binary Number** - A number from 1 to 32 is presented to the user and he/she must introduce, using 5 toggle switches, the correspondent number in binary;
2. **Coordinated RFID Cards** - The users must recover two RFID cards that they must use simultaneously on two RFID readers;
3. **Crypto Servo** - A letter wheel with an arrow that, given a ciphered-text that is introduced via a computer, points to the corresponding letters in clear text. (Implements the Caesar cipher);
4. **Telephone Exchange** - A panel with 8 holes, four on the left of the panel and four on the right, and an LED next to each hole that presents a color that has an equal on the opposite side of the

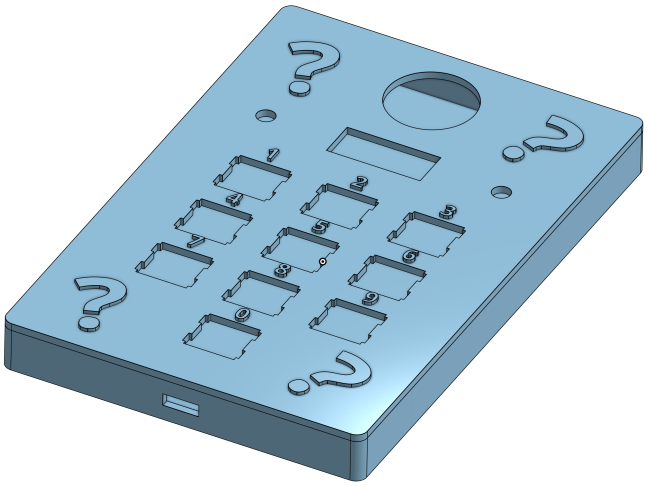

Figure 3.4: Enclosure of the Ordered Numbers interaction.

panel. A user must use 4 cables to connect each hole on the left to the hole on the right where the colors match;

5. **Keypad** - The user must use the keypad to introduce a secret code that he/she must discover;
6. **Light Sensor** - By using a light source, a user must shine light upon a light dependent resistor in order to trigger a certain threshold;
7. **Morse Code** - Using a randomly selected word from a limited set of hard coded words, a user listens to the Morse translation of that word and then must introduce the word in a computer terminal;
8. **Ordered Numbers** - A keypad with 10 keys, each one corresponding to a randomly attributed number. Through trial and error, a user must press the keys from 0 to 9 in order;
9. **RGB LED** - Using a D-pad, a user must introduce a red, green and blue value that ranges from 0 to 255 in order to solve this interaction;
10. **Digital Safe** - A small safe with two keyholes, two switches and one rotary encoder with a switch. The user must find the two keys in order to activate the safe and then introduce the correct code by listening to the faint sound of a buzzer on the safe that indicates when the introduced number is correct;
11. **Simon Says** - Replicating a popular pattern memorization game, this interaction produces sequences of numbers and sounds that a user must memorize and introduce in order to solve this interaction. It get progressively harder with each successfully introduced sequence;

12. **Ultrasonic Distance** - Through the use of three ultrasonic transducers, the user must position three tabs at certain distances that he/she must discover in order to solve this interaction;

The aforementioned interactions are the ones we will be using to create the Escape The Room experience but it is important to understand how, using these interactions, we have designed the game to be a re-playable and unique experience every time. The purpose of these design choice comes down to two reasons. The first is because we want to avoid that people who have played the game can repeat it and play it faster after having memorized all of the solutions to the interactions and achieve a better result than newcomers because of this.

The second reason is also related to the first in the sense that we want people that have played the game before to actually return and replay it while being able to experience it like it's the first time, even if the same interactions are used. We achieve this by randomizing the generation of the solutions which prevents returning players from memorizing them and getting an unfair advantage over other players. Simultaneously, we can re-use interactions since the feeling of having to search and discover clues and pieces of the solutions remains.

On the other hand, even though the solutions of the interactions are generated randomly, if a person has a fixed set of interactions that are solved in a fixed order, this too can contribute to an unfair advantage over newcomers. This brings us to another relevant aspect which is, the division of interactions in two types, primary and secondary, and the organization of the game by phases.

Regarding the organization of the game, we determined that, to be able to create a game that can be organized differently and autonomously in the future, we would need to have a way for the system to take all of the pieces of the game that are relevant to the players (Like pieces of a solution) and organize them in a way that makes it possible for the game to be played (For example, not allowing that pieces of a solution that is needed for an interaction in phase 2 be rewarded for solving an interaction in phase 5 that can only be solved by first solving that interaction in phase 2). To do this we designed the Escape The Room to be split into phases, as can be seen in fig. 3.5, with only the initial and final phases being the only ones that we impose some restrictions as to which interactions can be placed there. As made evident by fig. 3.5, the initial phase can only be composed of interactions that are of primary type and the final phase can only be composed of a single, secondary type interaction.

Before proceeding to explain how this organization by phases works, we must first explain the concept of primary and secondary interactions:

- **Primary interaction –** Can be solved by figuring out the logic behind its resolution without the person having to solve other interactions for this effect. An example of a primary interaction is the Binary Number where a user is able to solve it once he/she understands that the solution is to use the toggle switches to introduce the binary conversion of the decimal number presented on the 7 segment display.

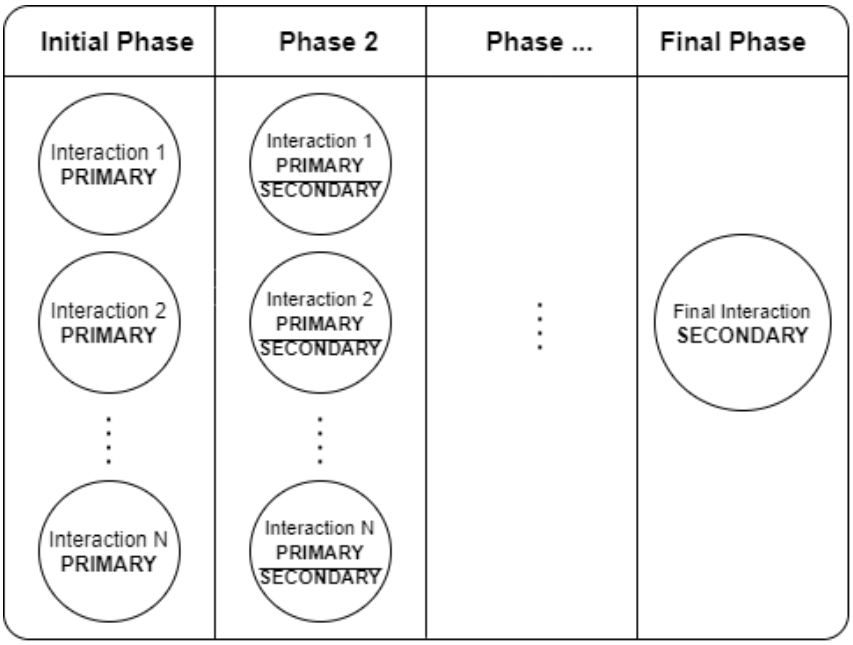

Figure 3.5: The structure of an Escape The Room game.

- **Secondary interaction –** Cannot be solved simply by understanding the logic behind its resolution. Instead, a user must find pieces of the solution or clues that point to those pieces by solving other interactions or by searching throughout the museum. An example of a secondary interaction is the RGB LED that needs a three piece code that must be obtained through the resolution of other interactions.

Having clarified the meaning of primary and secondary interactions, we can now explain the reason behind the constraints of the initial and final phase of the Escape The Room. The logic behind secondary interactions is that their solutions are split into several parts and these are then evenly distributed through the primary interactions of the phase those secondary interactions belong and all of the interactions of the previous phases. From here, we can understand one of the reasons why in the initial phase we are only allowed to have primary interactions because any secondary interactions that might be included in the primary phase would only have the primary interactions of that phase to distribute their clues through and if no primary interactions are included then the game would be initiated in an erroneous state that would not be possible to solve.

Additionally, there is also another, non technical related reason, that made us structure the game like this which is to give a starting motivational boost to participants. The ease of solving these primary interactions will motivate participants to move forward to solving the rest of the interactions of subsequent phases instead of running the risk of getting stuck solving interactions in the initial phase and consequently getting unmotivated to solve the rest.

The final phase only having a single secondary interaction is related to the fact that this is the in-

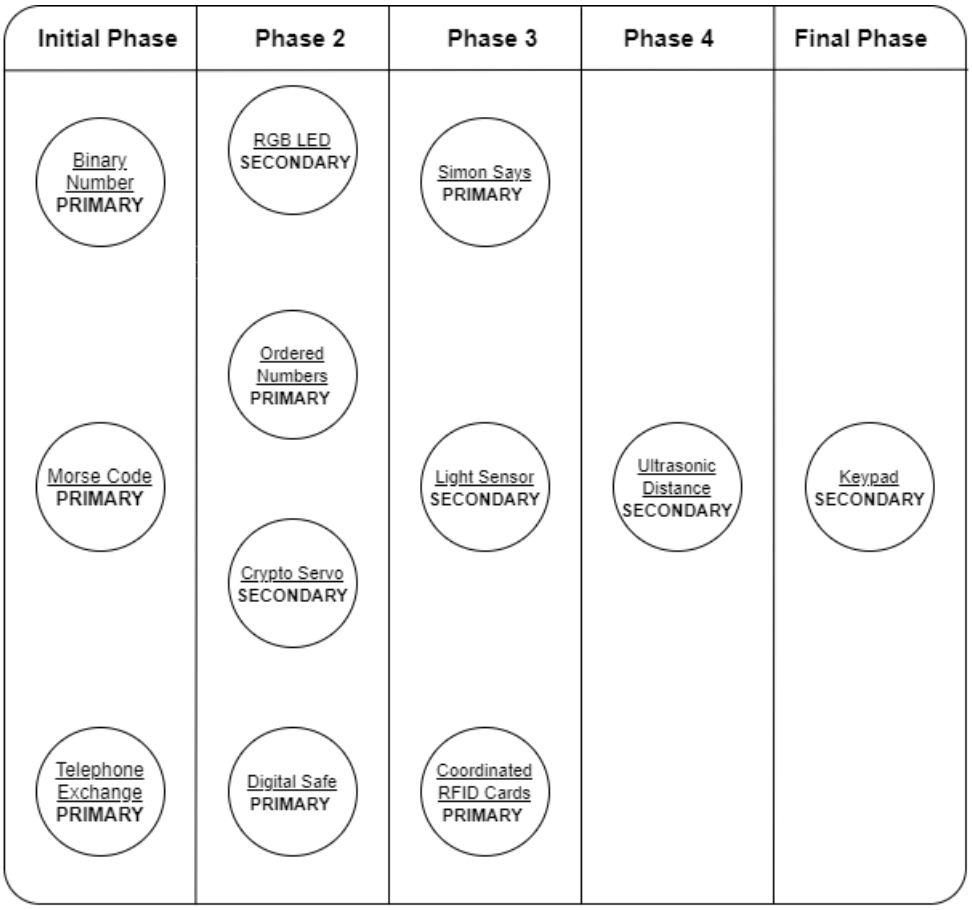

Figure 3.6: An example of an Escape The Room game using the developed interactions.

teraction that the participants are aiming at solving so that they can win the game. This implies that it cannot be a primary interaction, otherwise the participants would jump straight to it, solve it and the game would end. Therefor, it can only be a secondary interaction whose solution parts will have to be evenly distributed through the several interactions from the previous phases, providing a rewarding yet confusing feeling to players that will not, at first, perceive what the solutions/clues they are acquiring are for.

3.4 Synthesis

Understanding the architecture of both the Peddy-Room system and the Escape the Room that we designed is important to understand, in the following chapter, how we have implemented all of the relevant processes and system functoions as well as the Escape the Room that will leverage this infrastructure to try and prove if we were able to achieve the objectives of this work.

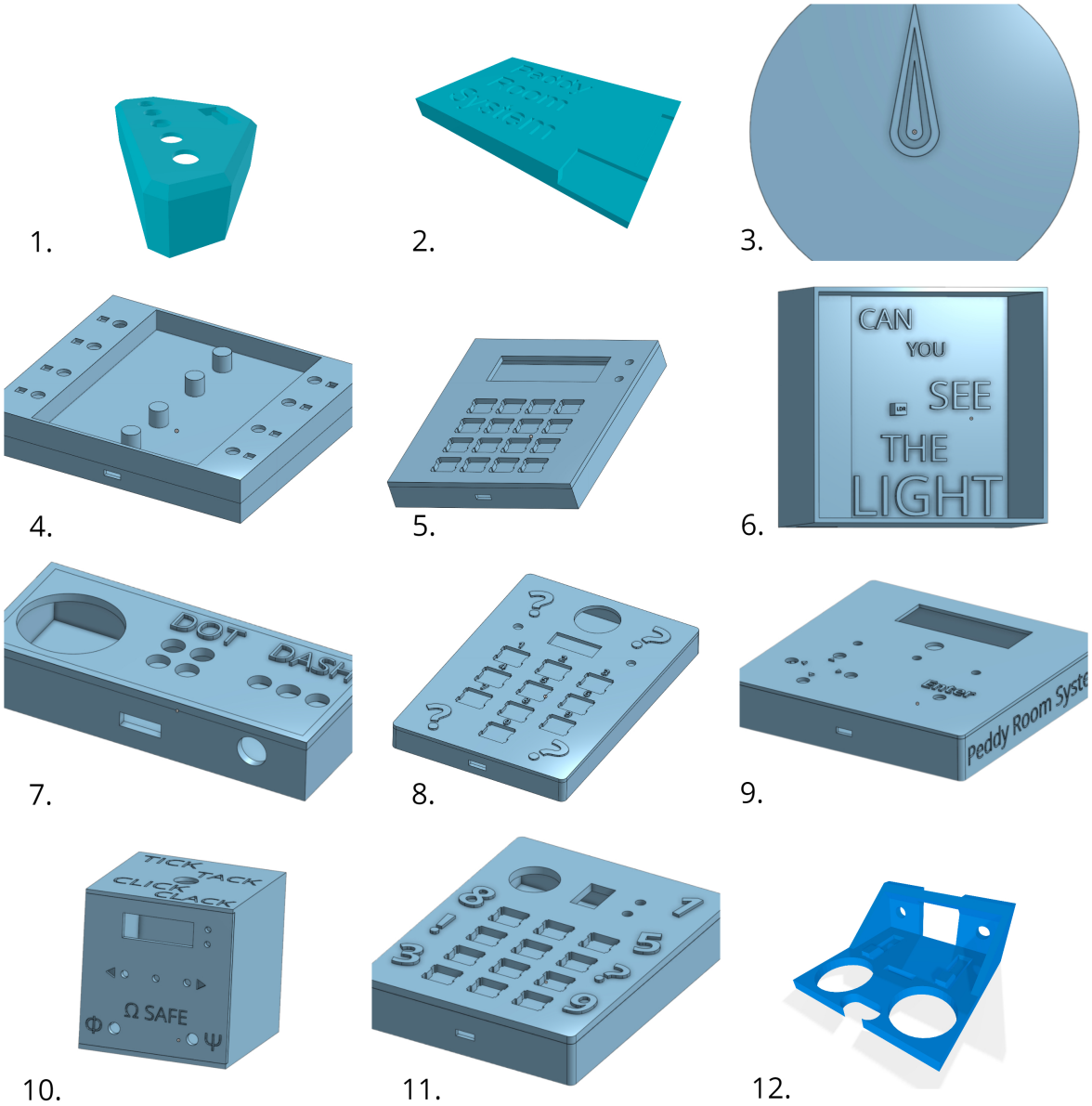

Figure 3.7: All of the prototype models designed that will be used to enclose the interactions.

4

Leveraging the Peddy-Room System

Contents

4.1 System Architecture Implementation

Having analyzed the overall design of the architecture of the Peddy-Room System (PRS), we can now detail our implementation of said architecture. We will begin by explaining the more general options we took like the chosen hardware to run both processes (gateway and collector) and interactions, as well as the programming language used to implement both of them.

4.1.1 General design options

Starting with the Hardware, this decision was influenced by several aspects that considerably limited our options. One of these was the fact that, according to the area of a museum, so varies the amount of machines that run the collector process. If a museum possesses a small area, then the amount of collector machines will be lower to cover all of the required area as opposed to a museum with a bigger area that needs more of the same machines. This is an issue due to the prices of the machines as well as their size. Price is a factor because we are aiming at building an affordable solution and, if a museum with considerable area to cover tries to adopt our solution and is faced with a substantial price barrier, that would drive away many possible adopters. The size of the machines is also an issue due to another of the requirements of this solution which is to blend in with the museum environment without ruining visitor's experience.

Lastly, we will also require a machine with sufficient I/O that allows us to connect our interactions to, in particular USB and general purpose input/output (GPIO) pins, so as to try and diminish the amount of collector machines that we need to deploy. Having these requirements into consideration, our most adequate choice is a Raspberry Pi 3 Model B since this is an affordable SBC that offers a set of different I/O interfaces such as the required USB ports and said GPIO. Additionally, it also includes wireless network interface cards for IEEE 802.11 and Bluetooth technologies and possesses dimensions (8,50x5,58x2,03) that facilitate the blending the infrastructure with the existing museum environment.

Still on the subject of hardware, the interactions that will connect to the Raspberry Pi's will also have dedicated hardware so as to provide real time feedback to the users, create a separation of concerns at the hardware level and having each type of device dedicate the entirety of its resources to a specific task. These devices will also have to comply with the same requirements as the Raspberry Pi's but do not need to be as powerful and expensive as the latter. As such, a single-board microcontroller such as the Arduino Nano that is equipped 22 GPIO pins[1] gives us significant resources when building the interactions, making it adequate for this purpose.

Regarding the programming language, we decided to use Java 8. Java allows us to abstract ourselves from the underlying hardware and OS when developing both the collector and gateway processes

[1] The number of usable pins is actually 20 since the RX and TX pins are unavailable due to serial communication between the microcontroller and the Raspberry Pi.

and has a wide range of open source libraries and frameworks that facilitate the development and maintenance of this solution. Regarding the interactions, the Arduino programming language was the one used.

4.1.2 Gateway

Using fig. 4.1, we will now explain the motives behind the chosen technologies and detail the implementation of the gateway process by explaining its functionalities and showcasing some of its components, like the web interface used to interact with the system.

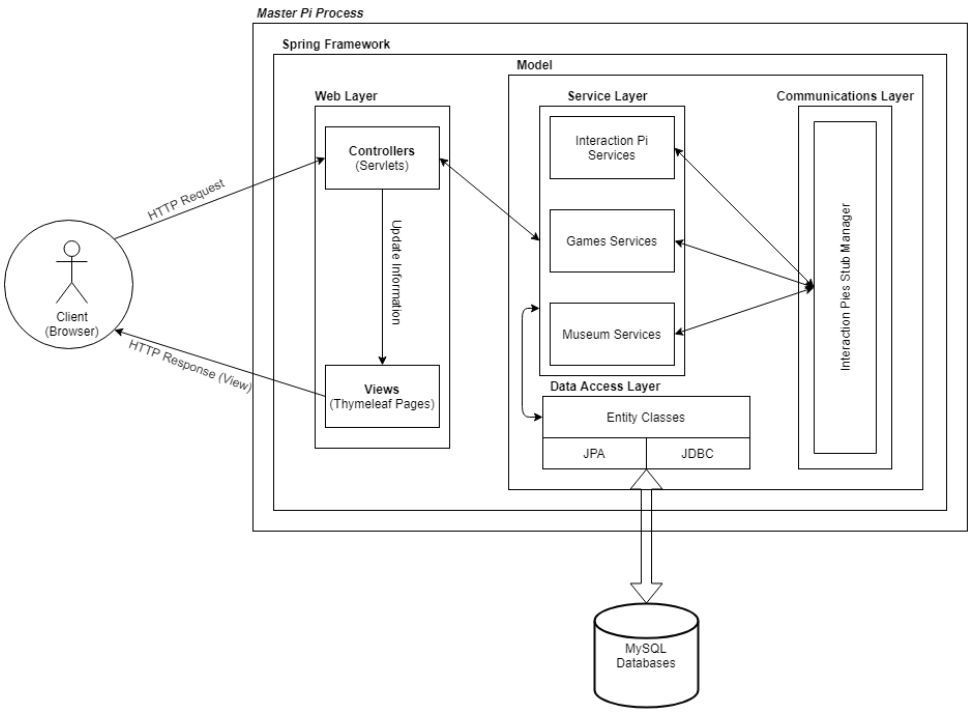

Figure 4.1: Implementation diagram of the gateway process with the specific technologies used.

Starting with the framework, we chose the Spring framework due to the features it provides that allow us to more easily implement the different functionalities of our solution while simultaneously not consuming a lot of resources from our already resource limited hardware. One of the features is the Spring Web MVC which facilitates the creation of web applications by implementing the MVC architectural pattern and providing components that allow the creation of a loosely coupled application. Consequently, this allows us to build the modular and extensible solution we were aiming at without having to write complex boilerplate code that would made the maintenance of the solution toilsome. Additionally, Spring also simplifies data access operations through the usage of ORM APIs (JPA, JDBC, etc...) which in turn allows easy and quick implementation of the data access layer.

4.1.2.A Implementation

The gateway process consists of a simple web interface that allows the user to manage and interact with the different parts of our solution. This process that is running on a Raspberry Pi provides the necessary endpoints to allow a user (museum staff) to execute the Escape The Room, manage all of the Collectors and get direct access to their interfaces and is where the game, the devices and sensors that are deployed in the museum can be monitored in real time to make sure that everything is working normally.

4.1.2.B Interaction Pies

We start by explaining the most basic feature of the Peddy-Room system which is the ability to connect to the collector processes, or Interaction Pies, that are scattered throughout the museum. Currently, this feature requires the user of the system to manually add the Interaction Pies every time the system is rebooted via the Interaction Pi services module on the service layer. To use this module the user will interact with the interface seen on fig. 4.2 from where he can choose to add an Interaction Pi or check all of those currently connected to the Gateway. Choosing the latter, he can remove or get access to the management page of the collectors where different, more specific functionalities of this process can be found.

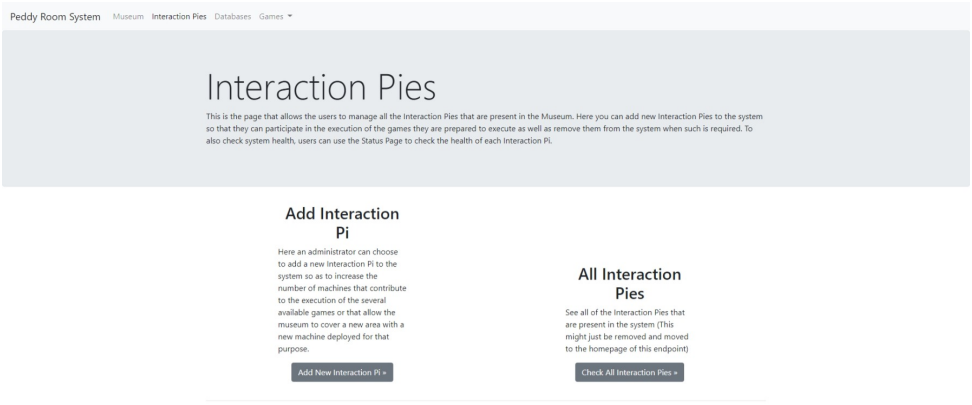

Figure 4.2: The main page of the Interaction Pi services from where a user can access all of the relevant functions of this module.

4.1.2.C Games

The Games Services module is the most complex module since it handles all of the functionalities related to the creation, deletion and management of games like the Escape the Room. This module does not possess a specific interface but will do so in the future to more easily and modularly accommodate

the addition of new games. For now, the user possesses a drop down menu (fig. 4.3) that presents the several games available and, from there, the staff can access all of the relevant functionalities this module provides, some of which are specific to each type of game.

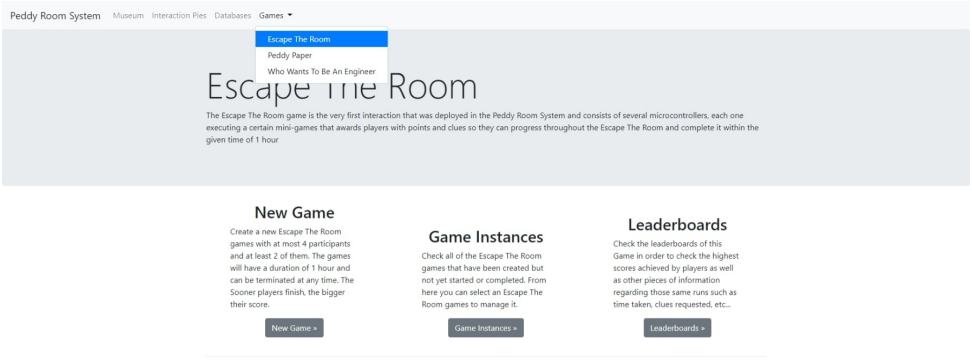

Figure 4.3: The Escape the Room interface where the more generic functions of the game are provided. Highlighted in blue is the selected game from the drop-down menu.

The generic functions implemented for the Escape The Room are the creation of a new game, the selection and management of previously created instances as well as allowing a user to get an overview of the status of each instance. Inside the management interface of an Escape the Room is where the specific options that are required for the correct execution of this game are present, some of which, need to rely on the Interaction Pies Stub Manager module to obtain information that is required for the setup.

Regarding the aforementioned specific features of the Escape the Room, we started by implementing the one that allows a user to input/change the name of the team that is going to play the game. The relevance of this feature is to allow teams to be identified by name so that these names, and the participants of the team, may be displayed to the museum visitors and to future players of the game so as to motivate competitiveness amongst teams and motivate people to return to replay the game.

We also implemented the basic management team features like the addition and removal of players. Given the current constraints the we imposed, a team must have, at least, two and, at most, four members in order for the game to start. Each player must also provide some basic personal information that will be stored in the database so that, in the future, an analysis of this data is made in order to reveal any points that can be improved or worked upon to further enhance the experience of visitors and players alike.

The set of features concerning the interactions that are to be included in a iteration of the game make use of the Interaction Pies in order to acquire the available interactions that can effectively be included in the game. During this process, it is mandatory to select which phase of the Escape the

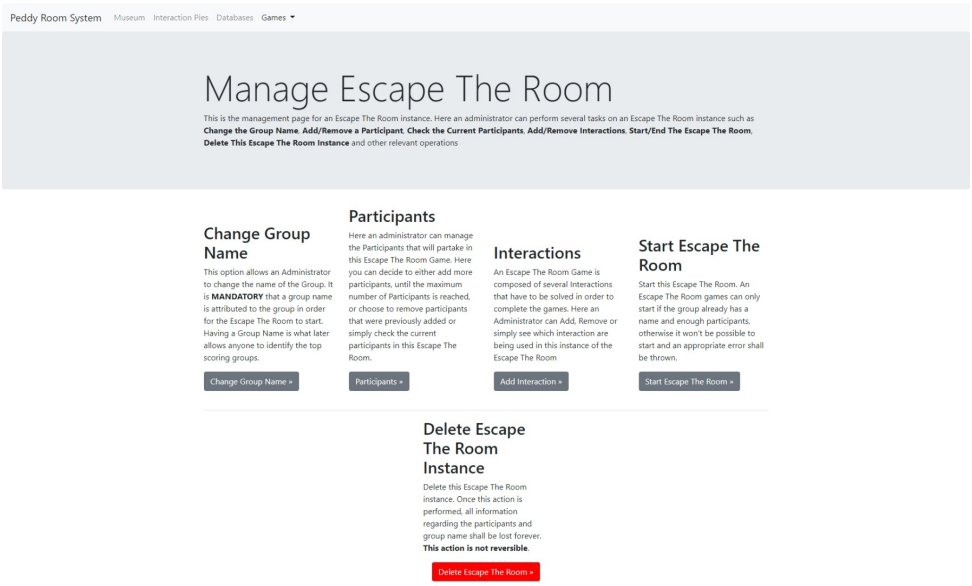

Figure 4.4: The interface used to setup and manage an Escape the Room game

Room does the interaction belong to. With the group having a name and enough participants, as well as the interactions required, the staff can start the game which, in turn, will send instructions to each of the Interaction Pies in order for them to create a local instance of the game and lock the interactions to that instance, preventing them from being used in another game. Additionally, there are also other, more basic functionalities, such as pausing the game if anything unexpected occurs, stopping it if the group decides to forfeit and deleting an instance if it is not supposed to occur.

Lastly, after starting the game, there is also an interface that shows a brief overview of the games' progress so that the staff may monitor the progress participants progress and check, for example, the time left for the game to end, the completion percentage and the group's current score.

4.1.2.D Databases

When it comes to the MySQL Database, several tables were designedfig. 4.5 to hold valuable information that will be used to improve the game and provide information to people outside of the museum, effectively eliminating the barriers between the museum and people outside of it. Starting with the escape the room table, this is where the information of each iteration of the game will be stored (Like the time it took to complete, the score achieved, etc...) and that will allow us to leverage that information to, as mentioned previously, stimulate competitiveness and motivate people to return to the museum to replay the game. The participant table is used to store information about the participants of the escape the room so that it can later be used for diverse purposes like contacting the user about information of the game or the museum itself and create a bridge of communication between the museum and its

previous visitors[2]. At last, the climate table stores information related to the temperature and humidity of the museum in its several rooms so that they can later be used in future analysis to improve the comfort of visitors while visiting.

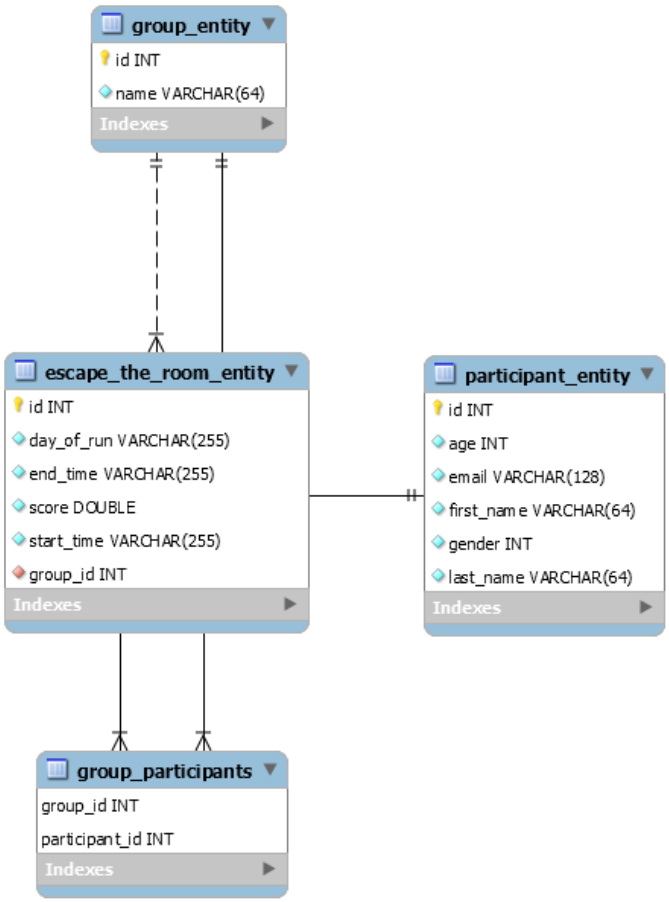

Figure 4.5: The Schema of the database

The usage of ORM APIs makes the creation and access of data a very easy and low code process that will later prove useful when attempting to expand the functionalities of the infrastructure or collect more data to perform further studies using/of the museum.

4.1.3 Collector

In chapter 3 we were able to observe that the architecture behind the collector and gateway processes does not differ greatly from one another. This is also reflected in the implementation of the collector that, as can be observed in fig. 4.6, also uses all the same technologies as the gateway process as

[2]The group table is used to group participant IDs in order to maintain track of the element of a team that played the Escape The Room

well as some additional ones that will handle all of the communication between the connected devices (Interactions and Sensors) and the collector.

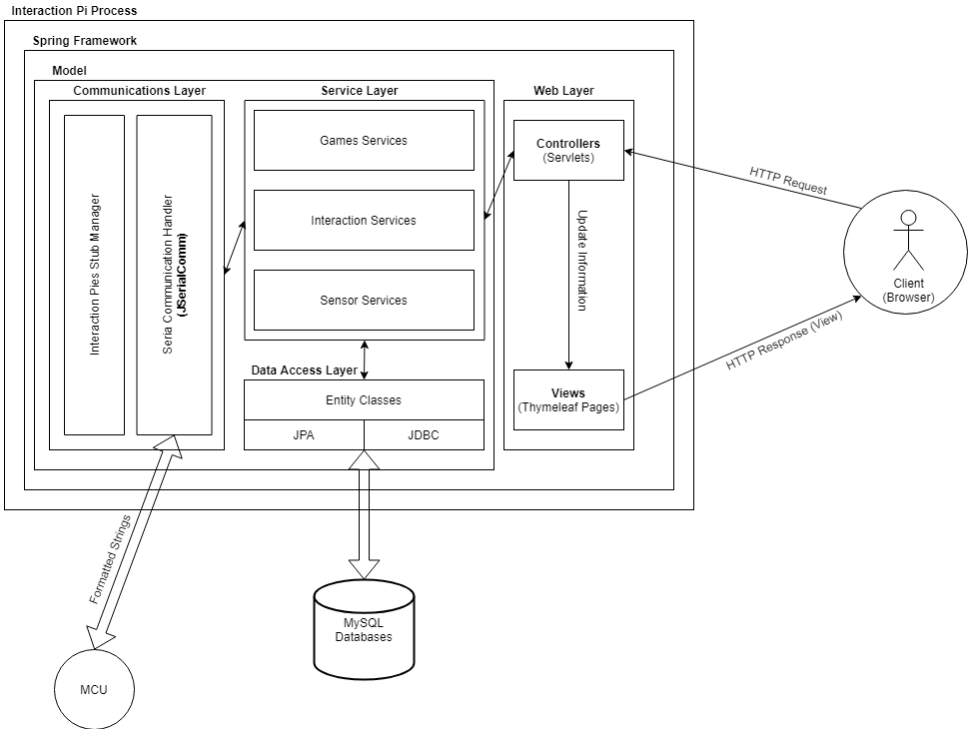

Figure 4.6: Implementation of the collector process showcasing the specific technologies used to implement the necessary system functions.

4.1.3.A Implementation

The collector process, from a user experience point of view, also consists of a web interface that provides the required functionalities to manage the devices, whether they are interactions or sensors, that are connected to that collector via USB. This interface can be accessed two ways, the first and intended one is via the gateway so that we have a central point of access to the collectors scattered through the museum. The second way is via a direct connection to the raspberry Pi which is used as a fail safe in case the collector loses connection to the gateway and cannot be accessed via the latter. This interface is very similar to the one found on the gateway, having only different functionalities that are related with the collector and the devices connected to it.

4.1.3.B Interactions

The interactions services is the most important module as it is the one that processes all of the messages sent by the interactions and provides the different functionalities found in fig. 4.7. Each of these functionalities will be explained in detail so that we can understand their relevance in the context of the

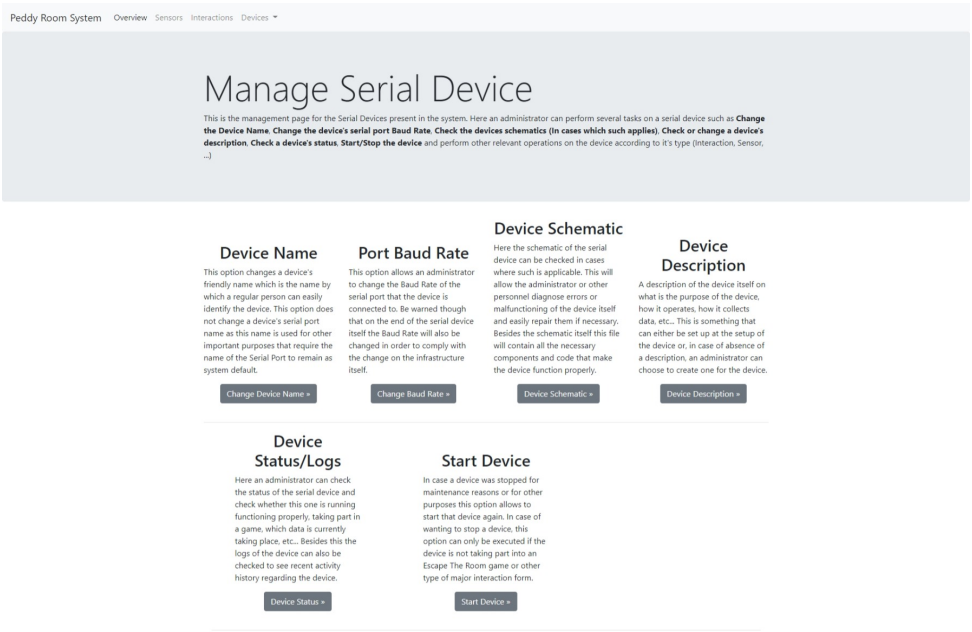

Figure 4.7: The interface that allows the staff to manage a serial connected interaction.

system as well as how they can aid staff in managing and identifying these interactions.

All the functionalities observed in fig. 4.7 for the management of serial connected devices (serial devices for short) are all common to the management of a serial connected sensor (serial sensor for short) with the only difference being the ability to change the frequency with which sensors report their values. One of these features is the ability to change a device's name so that it may be easily identified by the museum staff rather than using the standard name that comes programmed in the device. Additionally, we can also check the schematic of a device to aid in the diagnosis of problems and easily exchange components if needed. If the devices suffer changes, a new diagram can be uploaded to reflect said changes. Furthermore, there is also the possibility to change/add the description of a device to help understanding it.

There is also the option to check a device's logs so that we know what the device has been doing and what is reporting to the collector. This is useful from a development perspective since unexpected errors that may appear are reported and can then be used to improve the stability and performance of the system. Lastly, we also have the standard device functions such as the start and stop as well as a more specific one that allows changes to the baud rate of the serial port.

4.1.3.C Sensors

Regarding the sensors, their functionalities are exactly the same as the interactions with, as previously mentioned, the only difference being, the option that allows to change the frequency with which a device

reports its readings. It is worth stating that we have limited the frequency to a maximum value of one minute and a minimum of 1 second so as not to flood the serial port.

4.1.3.D Serial Communication Handler

The serial communication handler is the module responsible for receiving the messages from the devices connected to the collector, parse them and dispatch them to be executed. These messages come formatted and the fields that they possess can be seen below.

- **COM:** The instruction to be executed/acknowledged by the collector. Possible values:
  - **SETUP** - Sends information about the connected device (i.e. name, baud rate, connected sensors);
  - **START_ACK** - Acknowledgement to the start request;
  - **PING** - Ping to check if the device is responding;
  - **PAUSE_ACK** - Acknowledgement to the pause request;
  - **INTERACTION_SOLVED** - Command sent to signal that the interaction has been solved;
  - **STOP_ACK** - Acknowledgement command to the stop request;
  - **SENSOR** - Command that reports setup information about a sensor (i.e. type, frequency and connected I/O pin);
  - **READING** - Reports a reading from a sensor;
  - **FREQ_ACK** - Acknowledgement to the frequency change request;
- **MSG:** Informative message sent alongside some commands;
- **INT_NAME:** The name of the interaction;
- **BAUD:** Baud rate at which the device is reading messages from the serial port;
- **ID:** Unique ID sent in the request and sent back in the response (Used for response identification by the requesting thread);
- **PNT:** Points to be rewarded for solving the interaction;
- **PIN:** Pin to which a sensor is connected (Used for sensor frequency change);
- **FREQUENCY:** Initial sensor frequency;
- **TYPE:** Sensor type (Temperature, Humidity, ...);
- **VALUE:** Value reported by the sensor;

Using all of the above we are able to make messages like ”COM:SETUP;INT_NAME:Binary Number Interaction;BAUD:9600” that is used to execute the setup of the interaction called Binary Number which is communicating at a baud rate of 9600.

Listing 4.1: Algorithm responsible for evenly distributing clues through interactions

```
HashMap<String, Interaction> interactionsWithCluesAssigned = new HashMap<>();
int currentPhase = initialPhase;
while (currentPhase != (finalPhase + 1)) {
    ArrayList<String> clues = new ArrayList<>();
    ArrayList<Interaction> interactionsToDistributeCluesThrough = new ArrayLis();
    /*Gets the clues from the secondary interactions of the current phase*/
    for (Interaction interaction : interactionsByPhase.get(currentPhase)) {
        if (interaction != null) {
            if (interaction.getInteractionType() == InteractionType.SECONDARY)
                clues.addAll(interaction.getGeneratedClues());
            else
                interactionsToDistributeCluesThrough.add(interaction);
        } else { LOGGER.warning("Phase Skip Detected."); }
    }
    /*Get all of the interactions from the previous phases and add them to the
    array of interactions to distribute clues through*/
    for (int i = currentPhase; i >= initialPhase; i--) {
        if (i == currentPhase) {
            for (Interaction interaction : interactionsByPhase.get(i)) {
                if (interaction.getInteractionType() == InteractionType.PRIMARY)
                    interactionsToDistributeCluesThrough.add(interaction);
            }
        } else
            interactionsToDistributeCluesThrough.addAll(interactionsByPhase.get(i));
        if (i == finalPhase) {
            for (Interaction interaction : interactionsByPhase.get(i)) {
               if (interaction.getInteractionType() == InteractionType.SECONDARY)
                    interactionsWithCluesAssigned.put(
                        interaction.getInteractionName(), interaction);
            }
        }
    }
```

```
33      /*Evenly Distribute Clues in the clues array throughout the interactions
34      of the current and previous phases*/
35      int numInteractions = interactionsToDistributeCluesThrough.size();
36      int numItems = clues.size();
37      int cluesPerInteraction = (numItems / numInteractions);
38      int remainingClues = (numItems % numInteractions);
39
40      for (int i = 1; i <= numInteractions; i++) {
41          int extra = (i <= remainingClues) ? 1:0;
42          Interaction interaction = interactionsToDistributeCluesThrough.get(i-1);
43          for (int j = 0; j < (cluesPerInteraction + extra); j++) {
44              if (clues.size() == 0) { break; }
45              interaction.addCluesToReward(clues.remove(0));
46          }
47          interactionsWithCluesAssigned.put(
48              interaction.getInteractionName(), interaction);
49      }
50      currentPhase++;
51  }
```

4.2 Interaction Development and Assembly

Having understood how the overall system was implemented, it is important to also understand the development of the interactions and how they were made to interact with the infrastructure. We will start by explaining and showcasing the overall assembly of the interactions and the materials chosen to print them and then proceed to take a look at the common code each interaction shares that allows them to communicate with the infrastructure.

4.2.1 Manufacturing and Assembly

When the interaction were being designed, we had the purpose of making their construction as affordable as possible and easy enough to be replicated by anyone given that they have the proper equipment needed to do so. For this, we designed all of the interactions enclosures in a CAD software with the specific intention of making the models easily printable using an FDM(Fused Deposition Modeling) 3D printer which are becoming increasingly affordable. The models themselves, as could be observed in the previous section, are mostly box shaped enclosures that were designed with the purpose of concealing the elements of the interaction as best as possible to convey a more polished end result to the visitors.

Figure 4.8: The Binary Number interaction fully assembled.

Additionally, we can also hide sensitive parts of the interaction(wiring, solder points, etc...) to make them less prone to breaking due to the intensive use they will have, something that is expected to occur given the nature of museum environments.

Still on the topic resistance, the materials that are available for 3D printing are, nowadays, very vast and each of them convey certain properties that can then be used in favor of the interactions themselves. Given the requirements and the conditions to which the interactions would be subjected to, we decided to print all of the enclosures using PLA(Polylactic Acid), specifically PLA+ since this variant of PLA conveys more strength to the prints, making them withstand harsher treatments from the visitors.

Having all the enclosures printed, we assembled the interactions using components that are easily acquired in an electronics store. Given the lack of experience in CAD and 3D modelling, the enclosures did not feature elements that would allow access to the interior of the enclosure where all elements reside or provide proper fittings for the components, forcing us to glue the components, using hot glue, to the enclosure in order for them to remain properly seated in their place. This will convey more strength to the fitting of the components but on the other hand make it difficult to replace a component in the future if needed.

Besides the assembly, design and fabrication involved in making the interactions, there was also a lot of programming involved in their development. This programming can be divided into two parts, the first, which is common to all interactions, was establishing a common code base (library) that they would all share in order to communicate with the infrastructure. When developing this code we had to make it as simple as possible and to be easily extendable for additional functionality that the infrastructure might support in the future. The second part was all the programming that was related to the specific

Figure 4.9: Example of some components that are glued to the enclosure.

functionality that the interaction was providing. Partitioning the code allows us to develop the interactions in the way we see fit, eliminating the tight coupling between infrastructure code and interaction code.

```
1   void processReceivedMessage(char** command) {
2     if (strcmp(command[1], "START") == 0) {
3       startSequence(command[3]);
4     } else if (strcmp(command[1], "PAUSE") == 0) {
5       pauseSequence(command[3]);
6     } else if (strcmp(command[1], "STOP") == 0) {
7       stopSequence(command[3]);
8     } else if (strcmp(command[1], "INTERACTION_SOLVED_ACK") == 0) {
9       setInteractionSolved();
10    } else if (strcmp(command[1], "PING") == 0) {
11      ping(command[3]);
12    } else if (strcmp(command[1], "BAUD") == 0) {
13      setBaudRate(atoi(command[3]), command[5]);
14    } else if (strcmp(command[1], "SETUP") == 0) {
15      Serial.println("COM:SETUP;INT_NAME:Digital Safe Interaction;BAUD:9600");
16      Serial.flush();
17    }
18  }
```

Listing 4.2: Code responsible for processing infrastructure messages. Common to all interactions

Having acquired a deep understanding of the several components that make our solution and how all of them interact together to provide the experience we intend and achieve the results we expect, we can now determine whether or not we were successful in achieving the objectives initially set out for our work.

5

System Evaluation and Results

Contents

With all of the interactions built and infrastructure implemented, we will now discuss the steps taken to evaluate the performance of the interactions and of the Escape The Room which is built upon the developed infrastructure using said interactions. We will begin this chapter by briefly stating the hypothesis we are attempting to validate using the results our solution will gather. Afterwards, we will proceed to detail our experimental design and we will divide this into two parts, each one corresponding to the main two result sets that we gathered to improve and test, respectively, our solution. The first part will concern the interactions individually and the second one will concern the escape the room. Following this, we proceed to detail the demographics of the participants of the study, once again dividing this into two parts, after which we can explain the steps taken before each of the tests.

Following the analysis of the participants and setup of each of the tests, we can then proceed to analyse the the results collected as well as some of the limitations the results possess and, from there, we will close this chapter by analysing said results in order to determine whether or not we were able to validate our hypothesis, also taking the opportunity to discuss some limitations with our tests and solution that may have prevented us from acquiring better results.

5.1 Hypotheses and Research Questions

Throughout this work we have stated that the main purpose of our solution, the Peddy-Room System, was to enhance the experience of visitor's of a computation museum by the use interactive means, more specifically, through the use of an Escape The Room game composed of custom made interactions. We also mentioned that, even though this is our main focus with this work, we are also attempting to validate other aspects closely related to the visitor's experience such as the effect of having diverse types of interactions in the escape the room, as well as how these interactions are perceived individually as opposed to when grouped in the context of the escape the room. With this in mind, the hypothesis we will attempt to validate are the following:

- **H1:** The usage of an Escape The Room in a museum context enhances visiting experience and motivates visitors to return to the museum.
- **H2:** The diversity of interaction types in the Escape The Room positively contributes to the visiting experience.
- **H3:** Using interactions in the context of an Escape The Room better contributes to the visitors experience when compared to their usage individually.

While attempting to validate the aforementioned hypothesis we will also try and observe with the collected results some other, minor, aspects that are important to have a better understanding of the overall quality of our work and potential points of improvement that could have actually contributed to a

worsening of the user's experience. Starting with one of the aspects emphasized in chapter 2, we will attempt to validate if our participants felt the necessity of downloading any application on their mobile phone to be able to fully enjoy the escape the room and, if not, if they find this as something beneficial for their experience or not. Another important detail we will attempt to determine is whether or not our solution actually enables a bigger re-visiting rate, in other words, if by playing the game, visitors feel more encouraged to come back to the museum to revisit and replay the game as well.

Another important aspect which we will also attempt to measure is the learning experience that the visitors had during the escape the room. With learning experience we mean how they felt with regard to learning the subjects the museum had to teach using as complement the developed interactions that make up the escape the room. In the end, while attempting to validate our hypothesis as well as the additional components to the visitor's experience, we will end up also validating the Peddy-Room System itself with regards to it being capable of handling the escape the room and provide all of the management features which are relevant for the museum and the game itself.

Before attempting to validate all of the aforementioned points that are related more closely to the Escape The Room itself, we will first validate, with the users, the developed interactions that, together, will form the game. Validating these involves getting the users perception of their adequacy to be used in the context of a museum, if they are appropriate taking into consideration the overall theme of the museum (Computation Museum) and, in general, what do they think of the interactions regarding aspects like their build quality, dimensions, difficulty, enjoyment, etc... This way we will be able to improve the interactions in aspects deemed crucial before using them in the context of the game, allowing us to achieve better results overall and also allowing us to establish some baselines as to the effects of the interactions when used individually as opposed to using them in a game.

5.2 Experimental Design

5.2.1 The Interactions

In order to test each of the interactions individually we setup each and every one of them in the same order as the one seen in fig. 3.7 and invited people to go through each one and answer a set of questions that was similar for each interaction. The users would start by filling in some basic information about themselves after which they would proceed to solve the first interaction for which they would have complementary material (similar to the kind of material that one would expect to find in a museum) that would help them solve the interaction or, in the case it's an interaction that depends on others to be solved (the secondary interactions as we have explained previously), they would be given the required pieces of the solution that would allow them to solve the interactions.

5.2.2 The Escape the Room

The Escape The Room followed a similar approach to the interactions, the participants that would arrive in groups of at least two people and most four and each one would fill out an initial form with some basic information after which they would be made aware of certain aspects of the game. Following these initial steps they would proceed to play the Escape The Room after which they would finish the overall participation by answering some final questions about their experience.

5.3 Participants

5.3.1 The Interactions

When testing the interactions we managed to collect 24 individual results. The ages of the participants are comprehended between 18 years old to 27 with only two exceptions with 50 and 52. The majority of our participants, more specifically 75%, possessed superior studies and only 25% of them achieved possessed lower education levels but all in the upper secondary level. From these participants, the vast majority of them had studied computer science or other areas of study which are closely related to computer science with only 37,5% of them stating that their area of studies does not relate with computer science (or they simply did not reach a level of education where they were able to specialize themselves into a field of study).

To better understand how the participants felt about their knowledge in the subjects of informatics and electronics (Because even though a person's field of study may not be computer science or directly related to it, there could be a personal interest on the topic that gives people considerable knowledge about it) we asked them, in a scale of 1 to 5, where 1 stood for 'No knowledge on the topic' and 5 stood for 'Considerable knowledge on the topic', how much do they knew. We obtained no answers with the level 3 and, instead, had 25% of people stating they had no knowledge, 25% having good knowledge on the topic and 12,5% saying they know something about the topic. The majority of the participants (37,5%) stated that they possessed very good knowledge on the topic taking us to results similar to those observed with the field of study question since if we group these results into two major groups, above level 3 of knowledge and under, we will be faced with 62,5% of people having good to excellent knowledge on these topics and 37,5% having some to no knowledge. From here we can see that we possess a set of results where the users are mostly educated on topics that may conferee a competitive edge when solving the interactions and the majority of them within the age group of the 20s-30s.

5.3.2 The Escape the Room

With the Escape the Room we managed to collect 15 results, 12 of them belonging to groups of 2 participants and a single one belonging to a group of 3 people with 0 groups having 4 people which is the maximum number of participants per group allowed by the system. The participant's ages ranged between 18 and 50 years old with an age distribution as the one seen in fig. 5.1. Of these participants, 73,3% (11 people) were males while females only represented 26,7% (4 people).

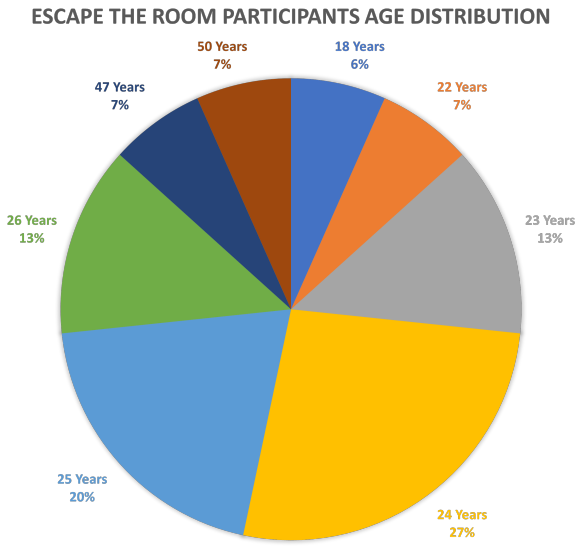

Figure 5.1: The age distribution of the participants of the escape the room

Once again, for the sake of understanding the results we might achieve far better, we inquired participants about their knowledge on computer science or any directly related engineering subject, like electronics, and we observed that, from our 15 participants, 26.66% (4 people) stated that they do not possessed any knowledge on these subjects while only 6.66% (1 person) said they possessed under the average knowledge on said subjects. Similarly to the participants that gave feedback on the interactions individually, none of these participants stated that they possessed average knowledge on the subjects. With regards to the participants with above average knowledge, we had 6.66% of participants (1 person) stating that they possessed above average knowledge on the topics of computer science and related subjects and, at last, the majority of the participants, 60% (9 participants), stated that they possessed a considerable amount of knowledge on the subjects the same as receiving formal education on them. If we apply the same division as before and group the participants in two groups, those with knowledge above average and those with knowledge under the average, we see that we have a population where, of the 15 participants, 66.66% (10 people) stated that they possessed knowledge on the subjects above the average while 33,33% (5 people) stated the opposite. Similarly to the population of the interactions,

this population is educated on these subjects with only a third of the population not having any to little knowledge on the subjects of computer science and/or other related fields of study.

5.4 Procedure

In this section we will document the procedure we took with participants before and after the individual testing of the interactions as well as of the Escape The Room. We will start with the interactions and then later proceed to document our procedure with regards to the Escape The Room.

5.4.1 The Interactions

The procedure we adopted for the interactions consisted of a small initial explanation of the objectives of the tests, followed by a brief form section where the participants would fill in some basic information before the testing started. This information is the information seen in the previous section were we detail the characteristics of our population. After this initial section the participants were informed of the rules they had to comply with during testing, never using any device or feature of allowed devices besides those allowed, and were also made aware of the additional material they had at their disposal during the resolution of the interactions. Afterwards, the participants were told to solve each interaction one by one and, after successfully solving the interaction, or giving up on their resolution, they were told to answer a section of the form corresponding to that interaction. They were informed that they would repeat this process for the 12 interactions and, after answering each section, they would answer a final section of the form containing questions about the overall experience. Following this debriefing, the participants were allowed to start testing each interaction in the order seen in fig. 3.7.

5.4.2 The Escape The Room

The procedure adopted for the escape the room was very similar to the one adopted for the interactions but there were significant differences that the participants needed to be aware of before and during the escape the room. For starters, the groups would arrive and an explanation would be given to them of the purpose of the experiment and they would be made aware of the time, at most, they would have to invest in order to fully complete the experiment. Followed this initial introduction and warning to the group, each member would proceed to fill a small, initial part, of a form, where they would introduce some basic information about themselves (age, sex, highest degree of education achieved, etc...) and would then proceed to fill out some sections of this form containing some questions related to their usage of technology, their behavior towards museums as well as the combination of technology and museums as well. Following this they would encounter a section instructing them to enjoy their experience and, it

was at this moment that the participants would start being briefed on several important aspects of the game, namely the rules, the time they had to finish, the devices and instruments they could use, the caution they had to have with regards to the interactions as well as the mechanisms made available to them to help the group progress through the game.

The participants were also made aware of the fact that they could, at any moment, forfeit the game if they were not able to solve an interaction, find something important that allowed them to progress through the game or even if they weren't enjoying the experience at all. Once the game ended, the participants would then be questioned in group of what they thought about the experience after which they would proceed to finalize the form they started filling in the beginning with some relevant information about their experience[1]. Additionally they would also be informed of their score and how their scored compared to other scores of groups that came before them (Something that was done in all groups except the first one due to not having scores, something that was explained to them after they finished the game)

5.5 Data Analysis

Both tests, to the interactions and escape the room, were conducted in a way where participants had to fill out forms with the information required by us that would then be subject of statistical analysis. For the interactions, participants filled each part of the form as they would solve the interaction. The time they took to solve each interaction was being monitored through the infrastructure and, as soon as they managed to successfully solve the interaction their time would be noted on the form. When it comes to the escape the room, the process was similar, the participants filled an initial part of a form with some basic general information about themselves and some of their behaviours and, after they finished playing, filled the rest of the form with information about their experience.

When all interactions were tested we conducted an open feedback talk with the users in order to understand their perception on the interactions, improvements that they felt like suggesting as well as things that did not go so well during the testing or the simply did not contribute positively to their experience. The same process took place for the escape the room.

5.6 Results

As it's been done throughout this chapter, we will be presenting two different result sets. The first will concern the interactions and the second will concern the escape the room. The first set of results will

[1] At this point in time we decided to not go through the interactions a group failed to solve with the group to explain to them what they missed in order to not extend the duration of the test and also to understand their points of view on the interactions

help us understand several key aspects related to the interactions such as their difficulty, their appropriateness to be used in a space like a computation museum, as well as other aspects that can be improved, either before moving on to the escape the room or as a future improvement. Not only this, but it is also a key point of interest to determine if the interactions alone can actually be able to provide a different degree of enjoyment to the people using them as opposed to only using them grouped in the context of an escape the room. Regarding the second result set, the ones concerning the escape the room, these will be the most important results for our work. From these results we will be able to validate our hypothesis since its mostly around the escape the room that our hypothesis are formed.

5.6.1 Interactions

When evaluating the interactions we focused the questions on several key aspects such as the dimensions of the interaction, the aesthetics, the difficulty of solving the interaction, how much the user enjoyed it amongst other aspects we deemed important not only for the interaction itself but also thinking ahead in the context of the escape the room. We will, throughout this subsection, detail the results acquired for each interaction and end this subsection by showing some additional results acquired within the context of these tests but now related to the visitor's experience more than to the interactions themselves. Unfortunately, due to the extent of the results related to the interactions individually, we will condense the results and rely on graphics to showcase them and occasionally detail.

Starting with the aesthetics of the interactions, we can see in fig. 5.2 that overall there is a very good acceptance of the interactions in terms of aesthetics and dimensions with the light sensor interaction being the most disapproved one out of the 12 which might come down to the fact that it's a very big box with a sensor inside which did not appeal visually to the participants.

Another important measure we monitored during testing was the time participants took to solve the interactions and, in the end, we made an average of those times which can be seen in fig. 5.3. From fig. 5.3 we can also see that, in average, the total time it took participants to solve all of the interactions was 59 minutes and 33 seconds which, in turn, allows us to expect good results when coming to the escape the room since the number of people solving interactions will, at the very least, duplicate and, at best, quadruplicate.

After participants were able to solve an interaction, they were inquired as to whether or not they found that the interaction they had just solved would improve their learning and visiting experience in the context of a real museum expedition and the results, which can be seen in fig. 5.4, show that the developed interactions show promising results as to the effects they have on visitors experience.

Difficulty is also a very relevant metric for reasons made clear in chapter 2 and, for that, we measured the difficulty of each interaction, as seen in fig. 5.5, as well as the enjoyment users felt when interacting with each interaction, which can be see in fig. 5.6.

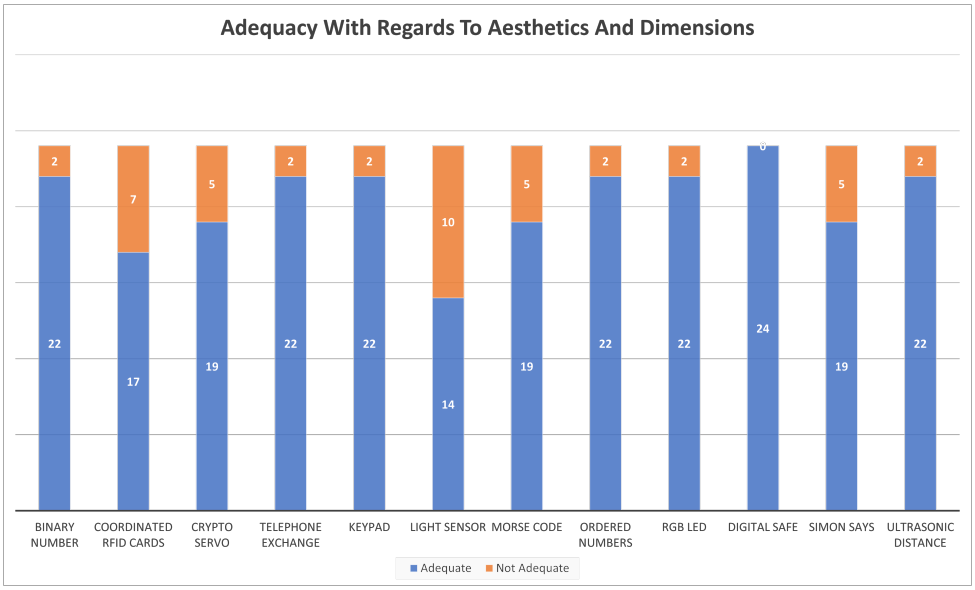

Figure 5.2: Adequacy of the interactions with regards to dimensions and aesthetics

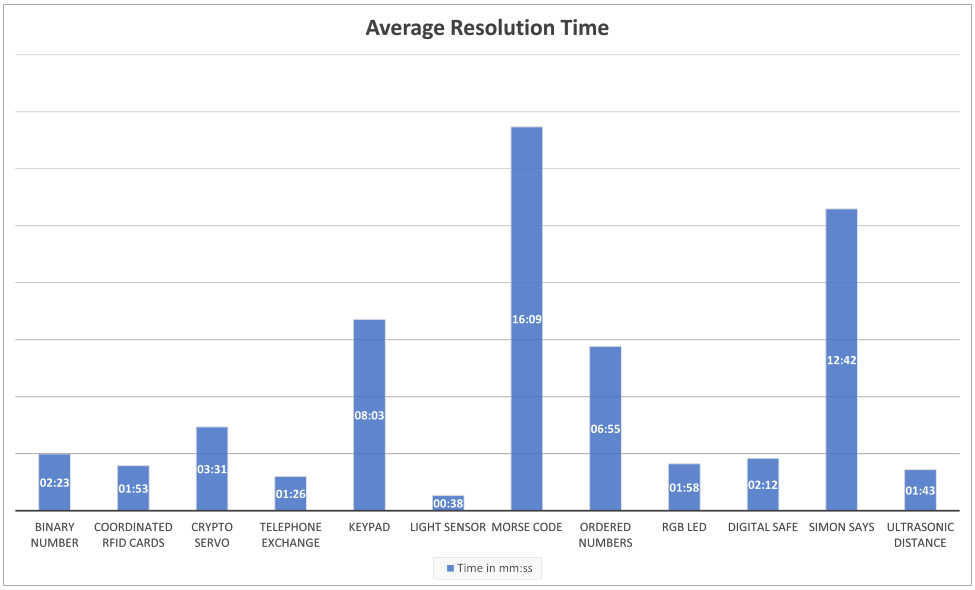

Figure 5.3: Average time it took participants to solve the interactions

Several other metrics were measured and they can be seen in appendix D but we will mention them and analyse them later throughout this chapter.

5.6.1.A Limitations

When it comes to limitations, we have several which do not allow us to have the strongest confidence in these results. The first limitation is the lack of users with a background knowledge that is not related in any way to computer science or similar subjects. What this means is that the results we have seen

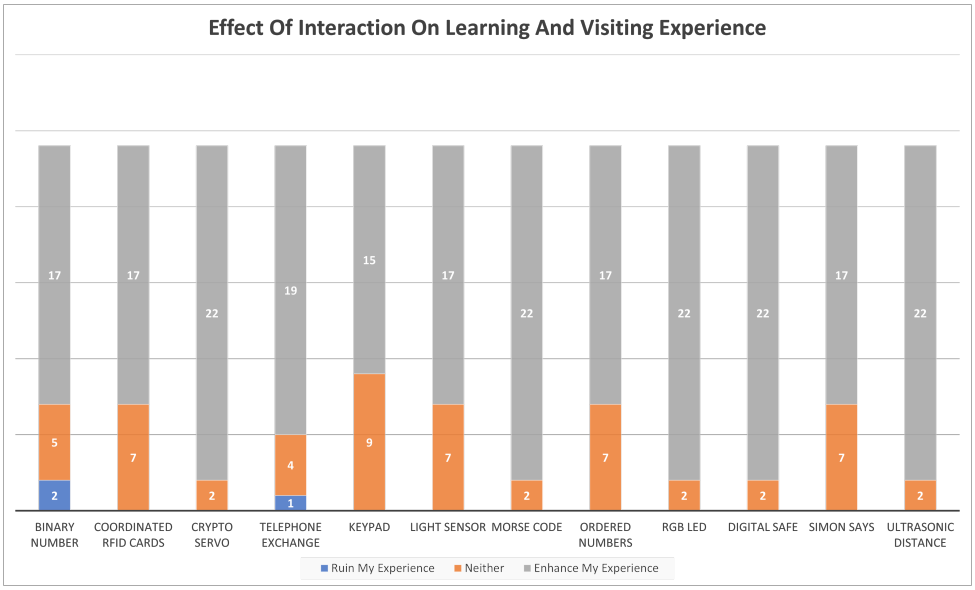

Figure 5.4: Effect that the interactions have on the visitors learning and visiting experience

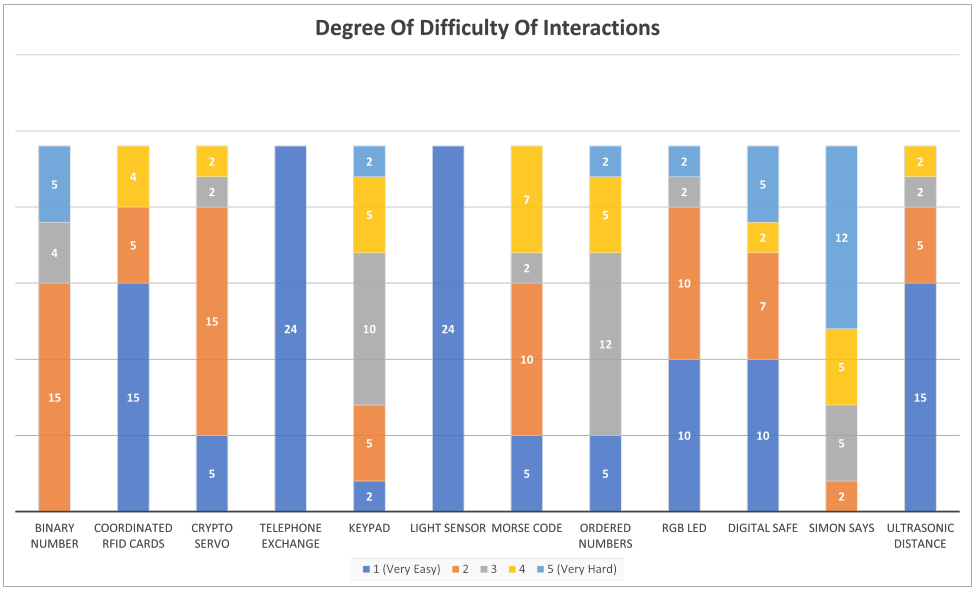

Figure 5.5: The difficulty of each interaction as perceived by the users

so far can provide us a good picture of the perception an educated user on these kind of subjects has but, on the other hand, we do not have enough data from uneducated users that allows us to say with confidence that these interactions can be enjoyed and solved with relative ease by people that do not understand a lot about computers or subjects related to computer science.

Another limitation of these results is also related with the end result of the interactions themselves. What is meant by this is that the interactions, due to severe assembly issues, were not able to look as they were initially intended to look which is with an entire enclosure that would cover their wires and

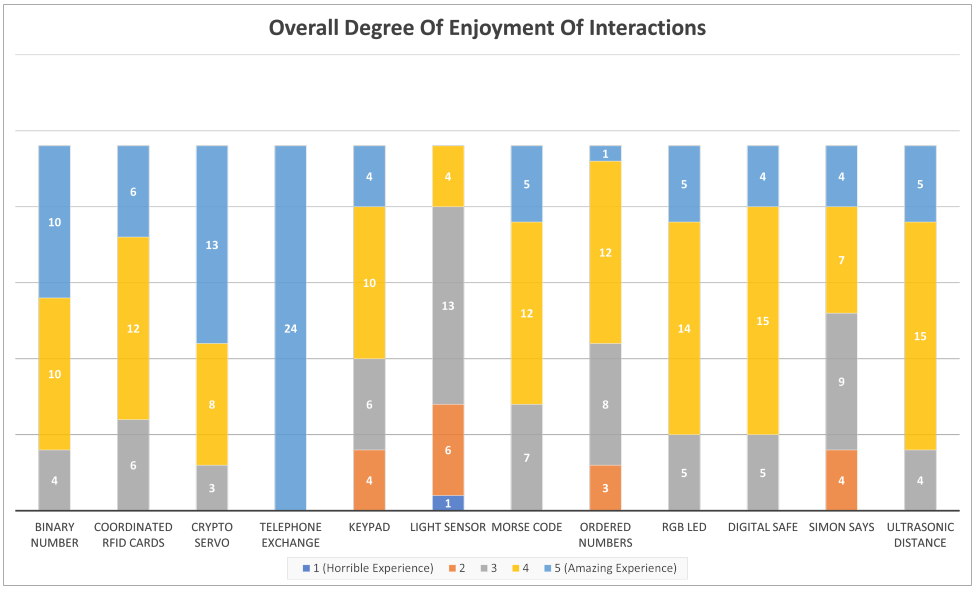

Figure 5.6: The degree of enjoyment felt by the users when interacting with the interactions

microcontroller and give the interactions a better look and feel as well as a more finished look. Since this was not possible, the users had a perception of the interaction that was very different from the one intended and also faced problems during testing where wires would sometimes come loose and things would stop working for no apparent reason.

The last limitation, which we also find important for the context of this work, was the environment where the testing took place. Due to several construction work happening at the computation museum in Instituto Superior Técnico (IST) it was not possible for us to deploy the interactions there in order to perform the testing. The reason why this becomes a limitation to our work is because it deprives users from the environment of a museum and the knowledge they could acquire from the museum directly by having pieces of knowledge integrated into the exhibit if need be.

5.6.2 The Escape The Room

When it comes to the escape the room, it's very important to start by showcasing the results achieved by each of the groups which can be seen in fig. 5.7. Following this data, we can now show the several relevant metrics supplied by the participants, individually, that we will then later on discuss in order to determine whether or not they validate our hypothesis.

The first metric we inquired users about was their overall degree of enjoyment to which we obtained the results seen in fig. 5.8. As we can see, more than half of the participants reported they had an overall experience that can be considered above average (considering that 3 is the score associated to an average experience) while only 40% reported having an average or bad experience with the game.

Group	Number of Elements	Score	Time	Interactions Solved	Hints Requested
1	3	0	01:00:00	10	3
2	2	0	01:00:00	4	3
3	2	0	01:00:00	8	3
4	2	0	01:00:00	7	3
5	2	13.479	00:53:39	12	0
6	2	15.924	00:42:00	12	0
7	2	12.807	00:57:00	12	1

Figure 5.7: Scores achieved by the groups as well as other relevant data about the game.

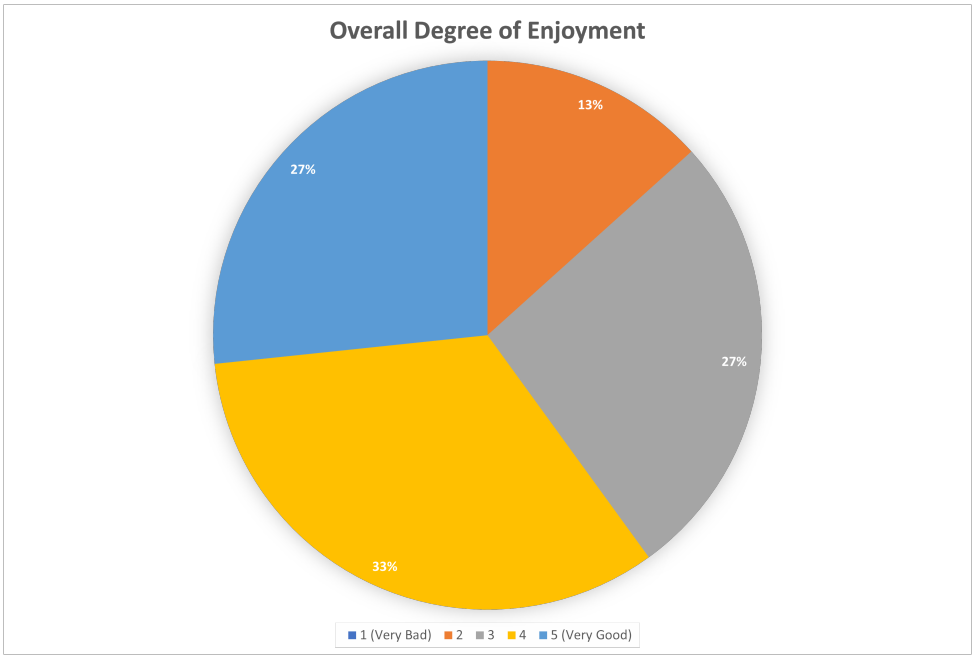

Figure 5.8: Overall enjoyment felt by the participants with regards to the escape the room

One aspect where all of the 15 participants agreed upon was the degree of interactivity where all of them stated that they found this approach to museum visits more interactive than what they are usually used to seeing in traditional museums. Where they did not coincide was in whether or not this bigger degree of interactivity was beneficial, harmful or even neutral to their experience. When it comes to this, we observed that 11 users reported this interactivity being beneficial for their experience while 3 of them reporting this as being neutral. Only one user stated that this degree of interactivity was actually harmful for their experience due to having to learn things ”under pressure” to be able to finish the game and score a high number of points.

Closely related to our work, and also a key factor to consider when it comes to the inclusion and enjoyment experienced by all visitors, we also inquired participants about how they felt regarding the different interaction types. The overall feeling regarding each of the three interaction types can be seen

in fig. 5.9 and we can observe that, from the three, the smartphone was the most disliked interaction type while tangibles stand out as the most enjoyed one. When asked about the effect of this diversity of interaction types as to whether or not it contributed positively to their experience, 11 users reported that it was a positive contribution while 4 stated that it was indifferent for them.

Related to this topic, we also asked participants whether or not, at any point during their experience, did they lack any feature on their smartphone that forced them to download an application that provided said feature. On this, all reported not having the need to download anything since their smartphone possessed all the required features for the escape the room.

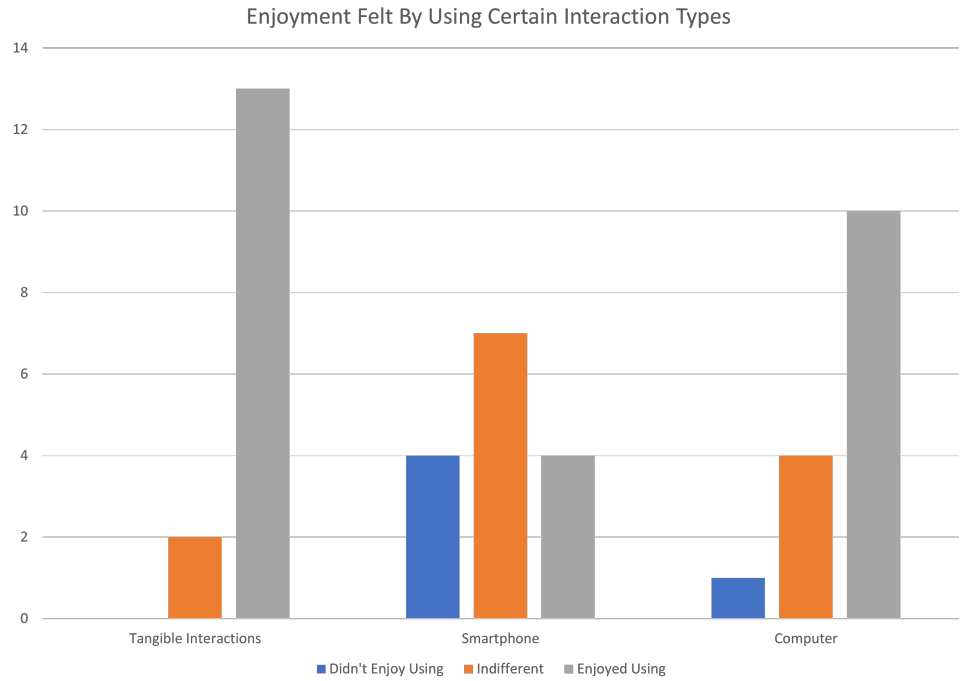

Figure 5.9: Enjoyment felt by the participants with regards to the diverse interaction types available to them during the escape the room

We also attempted to validate with participants that previously took part in the testing of the interactions if they found this way of using interactions, all bundled together into one escape the room game, more enjoyable than using the interactions individually as they did before. The results show that, from the 11 people that participated in both tests, all of them stated that they found the usage of the interactions in the context of the escape the room a more enjoyable way of using them as opposed to individually.

Regarding the most liked and disliked interactions, users were questioned about the interactions they enjoyed the most and least. The results show that the top three most liked interactions were the Crypto Servo, the Digital Safe and the Binary Number. On the other hand, the top three most disliked interactions were the Light Sensor, the Coordinated RFID Cards and the Ordered Numbers.

One important aspect we asked participants to clarify was their motivation to return to the museum to

replay the game and revisit the exhibit so that we can understand whether or not this approach actually managed to get people to revisit of feel like revisiting more than they would a traditional museum. On this, 13 participants answered that, with regards to the escape the room they had just played, that they would definitely revisit to replay the game while 2 of them answered that maybe they would return. After this we asked them to which museum would they be more inclined in revisiting, a traditional museum or one where the game and interactions they just used would be featured and all of them answered they would be more inclined in revisiting the latter.

5.6.2.A Limitations

When it comes to limitations with the results we have just showcased, we can say that these suffered from a lot of the same restrictions the results we showcased for the interactions did. Starting with the first and most harmful for this work, we did not manage to collect enough results to make more confident statements about what the results show. Since these tests were made during COVID-19 time, it was very hard to find groups of people that would be willing to test the escape the room. Not only that but finding groups of people willing to invest, at most, one hour and a half of their time to contribute with results for our work was also something difficult since many people simply did not have that time to spare. Again, we also did not manage to have a significant amount of results from a population with little to no knowledge regarding these subjects which will make it impossible for us to draw conclusions as to the enjoyment these people will have when playing our game.

Additionally, there is also the issue of the interactions themselves, as we've mentioned previously, the interactions are not in a state that can be considered ready to be exposed to an enormous quantity of users. Given this, there were many times where some interactions, more than others, would simply stop working completely because wires would come loose and that would require the game to sometimes pause in order for we to fix the issue and keep things going. By the end of all of the testing there was also the additional problem of the wear the interactions suffered where things that were glued together came loose, keycaps whose stem was broken and had to be reprinted, amongst other issues.

5.7 Discussion

5.7.1 Interactions

The individual testing of the interactions demonstrated that we managed to perform a good work when it comes to the aesthetics and dimensions of the interactions. These results actually allow us to say that in terms of the design and dimensions of the enclosures the work we did was actually good to be presented to the end users. There is some work to address on this since almost half of our interactions

were deemed not adequate 5 or more times and some users also provided feedback that was expected by us saying that a good portion of the interactions were all box shaped without any real character to them.

With regards to the time that took users to solve the interactions we would like to draw attention to the Morse code interaction where the average resolution time was 16 minutes and 9 seconds. This was one of the most frustrating interactions for reasons of bad development which then led to a small adjustment before we used it on the escape the room. The issue was that the time between dots and dashes on this interactions was set for a professional hear and not for regular people that are not trained to understand Morse code. This then led us to adjust the timing after the testing so that people would not get frustrated so much in solving this interaction. With regards to the Simon Say's interaction this one proved to be very difficult for users since they were not able to understand what was the logic behind the interaction and this led them to the creation of several theories during the resolution which increased the time it took for them to understand that it was a simple pattern recognition game. This was a positive result since the interaction was easy enough to solve but confusing to the point where people would go far beyond what was expected, not realizing the simplicity of the solution and ending up investing more time than we could have anticipated with this interaction.

When it comes to the effects that the interactions caused on users, we saw in fig. 5.4 that we successfully managed to develop interactions that conveyed a positive effect on our users since the majority of them, in all interactions, stated that the interactions had the ability of enhancing their experience both in terms of visiting experience as well as learning experience and, surprisingly, for the same reason which was the fact that they were able to learn a theoretical topic but having a practical way of also learning that subject. Unfortunately, in the two interactions where a few users stated that they ruined their experience we were not able to collect from them any answers as to why this happened.

On a more technical approach, we were also able to determine that both the infrastructure and the interactions themselves were developed in such a way the the feedback times were all very good in our user's opinion and the feedback itself was also clear as to the message it was intending to convey, whether that be the input is wrong or right.

In the end we were able to fix some issues with the interactions and perform some improvements both construction and code wise before proceeding to test the escape the room. Not only that but we also were able to determine that the interactions, as a standalone option to increase interactivity in a museum, also provide good results when it comes to visitor enjoyment and learning experience, validating one of the approaches we had for this work which was using the interactions individually without the need for an escape the room. On the other hand we also saw during this testing that the infrastructure was not developed appropriately for two of the interactions which were the Morse Code and Crypto Servo which harms this approach of using the interactions individually.

5.7.2 The Escape The Room

Coming to the results that are most relevant to our work, we will start by first addressing our first hypothesis ”The usage of an Escape The Room in a museum context enhances visiting experience and motivates visitors to return to the museum”. This first hypothesis can be considered one of the main objectives of this work and we saw through fig. 5.8 that overall we achieved a 60% of above the average enjoyment from our participants with only 13% stating they suffered from a bad experience. These results are very positive for us considering the fact that more than half of our participants were not able to finish the game and still we achieved a positive degree of enjoyment from 60% of participants. This does, in fact, validate the first part of our first hypothesis as data shows that the escape the room we developed enhanced the visiting experience of participants. With regards to the second part, we also see that 13 out of the 15 participants stated that they would revisit for the purpose of playing but the missing two stated that the might revisit as well, not ruling out the possibility. With this data we can confidently say that our first hypothesis is validated and the escape the room we developed was able to enhance visitor’s experience as well as motivate them to revisit for the purpose of playing again.

Coming to the second hypothesis, ”The diversity of interaction types in the Escape The Room positively contributes to the visiting experience” we stated this on the premise of what we learned in chapter 2 that we should strive to have several types of interactions that people of different visiting styles and with preferences for different devices can enjoy so as not to deprive them from having a good experience just because our game lacked interaction types that they enjoyed more over the others. Seeing the results, we saw a clear dominance of the tangible interactions in terms of enjoyment, followed by the computer and then, in last place with the ”indifference” feeling dominating, the smartphone. In the end, of our 15 users, 11 reported that they found this diversity to be a positive aspect in their experience but there were users that stated that both the smartphone and computer were not explored to the full of their potential and felt more of means to an end than actually interactions. To conclude, given the results we collected, we can also confidently say that our second hypothesis is also validated given that all but four users stated that the diversity positively contributed to their experience.

The last hypothesis, ”Using interactions in the context of an Escape The Room better contributes to the visitors experience when compared to their usage individually” was also one we were able to validate with our users. Unfortunately for our results, we only managed to have testing the escape the room 11 people that also tested the interactions individually but, from these, all of them stated that they enjoyed using the interactions when in the context of the game as opposed to using them individually.

5.8 Limitations

Our study suffered from several limitations related to the COVID-19 pandemic, the development of the interactions and the fact that we could not deploy this in a real museum with actual visitors. Starting with the pandemic, this considerably affected the amount of participants that we had to test our infrastructure and game. Even though the participants we had were able to provide valuable insights about our approach, an increased amount of results would allow us to cover more defects of our system and gather more feedback that would grant a bigger degree of confidence to the results we were able to collect. Additionally, having to follow all of the sanitary measures (Disinfecting the interactions and surfaces that visitors would be touching) implied that we could not perform as many runs of the game in a day as we were expecting.

With regards to the lack of experience in CAD and printing, the plates that were designed for the interactions did not possess enough tolerance for the components that were to be assembled on them. This made us perform some interventions on the plates themselves, that, in some particular cases, caused severe damages to some of the placeholders of the components, ruining not only the integrity of the interaction but especially the aesthetic of it to the users. This can be observed, for example in the Simon Says interactionfig. 5.10 where damage due to the usage of a rotary tool to widen the cutout of the 7-segment display can be seen and even implied the usage of hot glue to fix the display in place. Another drastic example of the consequences of lack of experience in CAD are also visible on the telephone exchange interaction where the lack of tolerances prevented us from hiding key components of the interaction in their place and instead had to be visible to the users.

Furthermore, the design phase of the enclosures of each interaction was done in a very simplistic way making it so that almost all of the enclosures are very simple geometric shapes designed to enclose the circuitry and components of the interactions. This, in turn, can become dull for the visitors since each interaction will seem like a variation of the others instead of looking like something entirely different.

Still on the topic of design, the enclosures were all designed with a plate and case in mind where the latter would have the single purpose of hiding the wires and MCU so that these are not exposed to the hands of visitors and therefor avoiding unnecessary risks to the interactions. Unfortunately, when the enclosures were fully printed, we quickly concluded that, in order to try and make the interactions as discreet as possible, the dimensions that we used were not sufficient to hold the cables and MCU inside the case. This was also aggravated by the assembly of the electrical connections of the interactions since the dimensions of the cables and their routing quickly created a big volume beneath the plate, even in the most simple of interactions, making it impossible to fully assemble the enclosurefig. 5.11.

Figure 5.10: Damage sustained by the Simon Says interaction when attempting to widen the cutout 7-segment display cutout.

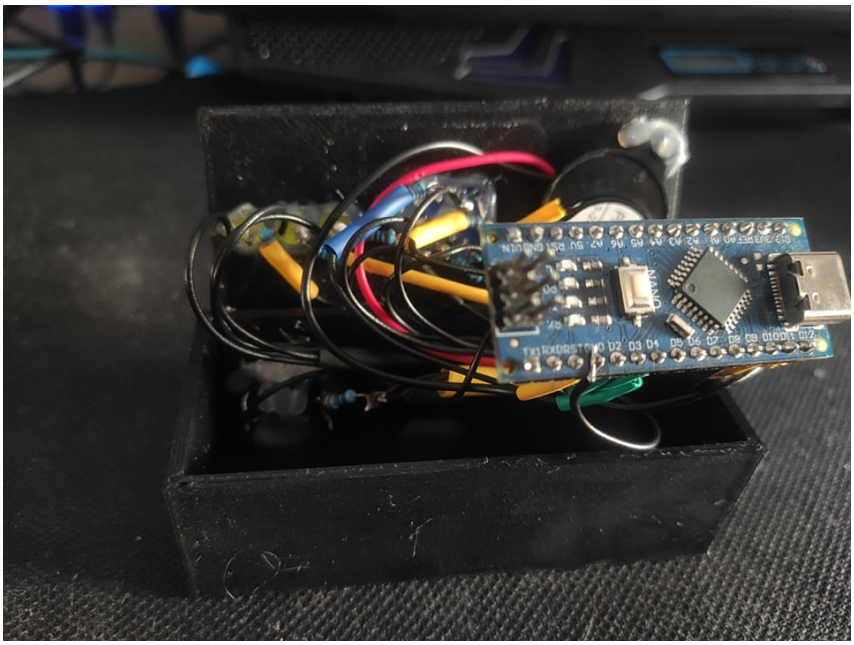

Figure 5.11: Morse Code interaction fully assembled, not having enough space in its case to fit the wiring and MCU

6

Conclusion

Contents

6.1 Conclusions

With this work we managed to develop a solution which consisted on a custom built infrastructure running on affordable hardware that supported an escape the room game that was developed using interactions developed also for this work. Using all of this, we managed to establish, with the results we collected, that all of our hypothesis were valid and in fact our solution was able to fulfil the objectives it initially had set out to. We saw that the escape the room managed to enhance visitor's experience and became a key factor in their motivation to revisit the museum. We asserted that the diversity of interactions we aimed at having in our solution also played a positive role in the experience with users stating that this diversity contributed positively and, at last, we saw that, even though we support both approaches of using the interactions in the context of the escape the room and individually, users have a clear preference for their usage collectively in the game.

There is also a severe amount of work and improvements that must be done, something that almost all participants made us aware and that we will consider for matters of future work.

6.2 Future Work

Throughout the development of this work we realized that there are several issues and quality of life improvements that can be implemented for both the infrastructure and interactions alike. Furthermore, there are also several other important topics that can make use of museum environments and of our infrastructure(alongside the Escape The Room) that we intend to study.

6.2.1 Infrastructure

Starting with the infrastructure related improvements, the first aspect that needs to be addressed is the improvement of the interfaces that are presented to the staff/participants. These interfaces are poorly designed when we take into consideration best practices of interface design and they are not consistent in the presentation of errors and messages of feedback. Alongside these issues and moving to a more aesthetic related one, the interfaces have very poor CSS built into them and are not pleasant to look at, worsening the participants experience. A major change that will also be made is replace the usage of Spring, a server side rendering technology, for a front-end framework like React that will allow a more decoupled development from the back-end. This leads us to a consequential refactoring of the back-end since to serve content to the front-end we will implement a REST API that can more easily serve content to the front-end and is also better prepared to serve content to other types of devices if such is required in the future.

Another minor but none the less important improvement is the implementation of service discovery

so that the Interaction Pies can automatically connect themselves to the Master Pi. This improvement is deemed as important for us because a big downside of our solution is that every time something wrong occurs that causes an Interaction Pi or even the entire system (Power outage for example) shut down it implies that someone has to manually add each Interaction Pi to the Master Pi as well as add each interaction/sensor to the interaction pies they are connected to. This last part is also something that we will improve upon to make the devices automatically register themselves in the infrastructure once they are connected to an Interaction Pi since what happens currently is that after connecting a device via USB there is still the need to manually add that device to the system via the interface of the Interaction Pi.

6.2.2 Interactions

Following the improvements to the infrastructure, there are also several improvements to be made regarding the interactions. The first improvement that stands out the most to visitors is the overall design and build quality of the enclosures of the interactions. For this first iteration of our solution the enclosures designed and 3D printed lack a lot of quality and suffer from a lot of flaws. Quality wise a great majority of the enclosures are too brittle and can break easily, an issue that relates to both the design and the material (PLA+) used for the enclosures. This is a major point of improvement when we factor in that these interactions will be placed in an environment where a lot of people will be handling them daily and a museum cannot afford to have interactions down for maintenance constantly because an enclosure broke. Additionally, there is also the issue of making the interactions easy to modify and replace components. Currently, the interactions are being glued together and this limits/makes it difficult for anyone to replace a certain part of the enclosure or a broken component of the interaction since some of the components are also being glued into place.

Following the previous functional improvements, we also intend to improve upon the aesthetic of the enclosures. Currently, the enclosures were all 3D printed in black PLA+ which also worsens participants experience as the interaction seem out of place when we take into account the surrounding museum environment.

6.2.3 Interaction Types

The last subject we are going to work on is increasing the number of interaction types present not only in the museum environment but also integrated into our Escape The Room and infrastructure. We have mentioned throughout this work that interaction diversity is a key aspect in developing an interactive experience at a museum since different people prefer to interact with different types of interactions due to their own visiting style. With this in mind, we intend to, in the future, include interactions like Virtual and

Augmented Reality which are, as previously seen, rising in popularity and usage and that can provide a completely new and different dimension to a museum visit and to an Escape The Room.

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A

Preferred Mediums to Learn History - Survey Results

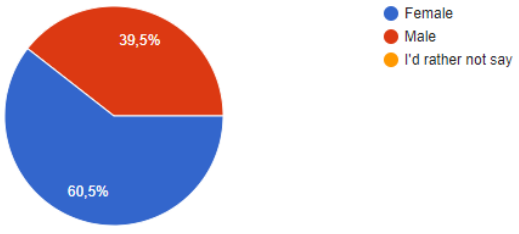


Figure A.1: Gender Distribution of survey respondents

Here we can see in more detail the results of the survey that was conducted in order to conclude what are people's preferences regarding mediums that teach history and, of these, which do they consider more fun and motivating. The result had a total of 38 responses. As can be seen in fig. A.1, of these 38 answers, 60,5%(23) of them were female while the remaining 39,5%(15) were male. The majority (68,4%) of the respondent's ages were comprehended between 16-24 years old so we have bigger portion of the respondents belonging to the generation Z, also known as the Zoomers, while the rest of the respondents had ages between

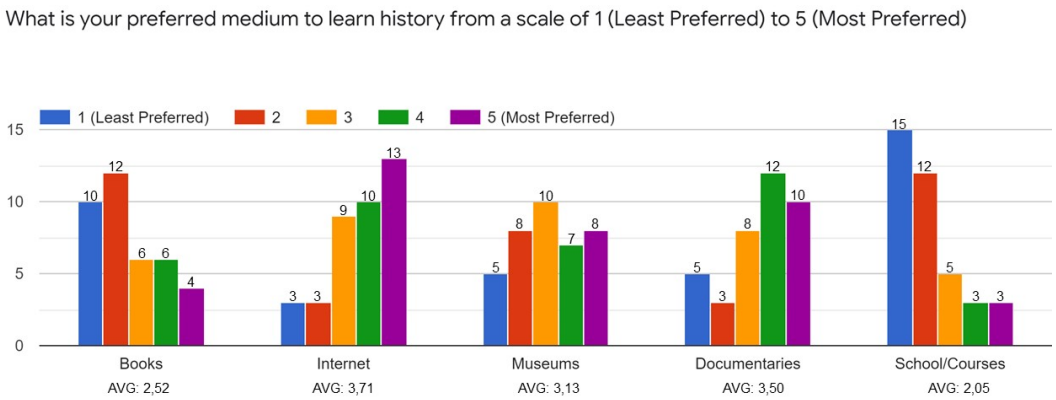


Figure A.3: Responses to the question "What is your preferred medium to learn history"

the 25-44 (28,9%) or were under 16 (2,7%).

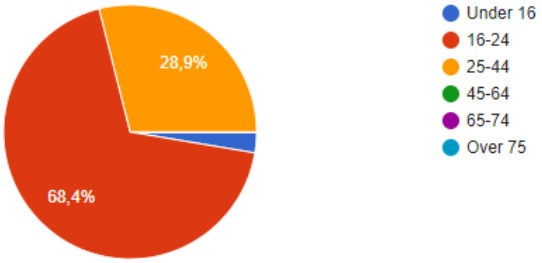


Figure A.2: Age Distribution of survey respondents

Now, regarding the first question of the survey, **What is your preferred medium to learn history**, the results, which can be seen in fig. A.3, we observed that museums, in the traditional way they operate nowadays to entertain and educate people, are positioned in third place in terms of people's preferences regarding the medium to learn history. In front of museums we have documentaries and the internet occupying the second and first place respectively. These results show that the majority of the respondents have a preference for mediums that are digital based instead of those that are less/not digital based, something that can be justified by the averages of the two most undesirable ways of learning history, books and school/courses.

Moving on to the second question, **Which medium provides you the most fun when learning history**, here the results are similar to ones observed in the first question. Once again, the internet and even documentaries, to our surprise, surpass museums in terms of the fun they provide people when learning about history. These results come as a surprise to us since we were expecting museums to be competing for the most fun place to learn history alongside the internet. This data is rather alarming and

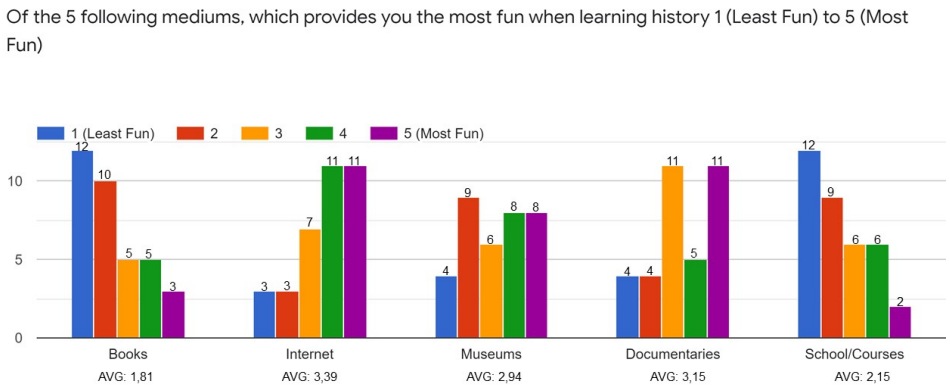


Figure A.4: Responses to the question "Which medium provides you the most fun when learning history"

is aligned with the study [16] that states that the second highest barrier to visiting heritage sites (of which museums are part of) is the lack of interest in visiting them. This was the second most voted option, just below 1% of the highest voted option which is lack of time. People's lack of time is something that we cannot control or influence but their lack of interest towards museums is an alarming evidence that enough work is not being done in order to attract visitors nowadays.

Regarding the final question, **Which medium motivates you the most to learn more about history**, the results once again remain similar to the first two questions. The internet scored an average value of 3.24, followed by documentaries with an average value of 3.18 and then again museums in third place with an average value of 2.92. The results from this survey allow us to draw several conclusions, one of which is that digital mediums have greatly surpassed traditional ways of learning history (Books, School and Museums) in all three mentioned aspects. This is a warning sign that changes have to be made if we intend for museums to compete with the internet and documentaries as a medium that surpasses either of the two or even both in any of the three mentioned aspects.

B

Interaction's Metrics - Graphs

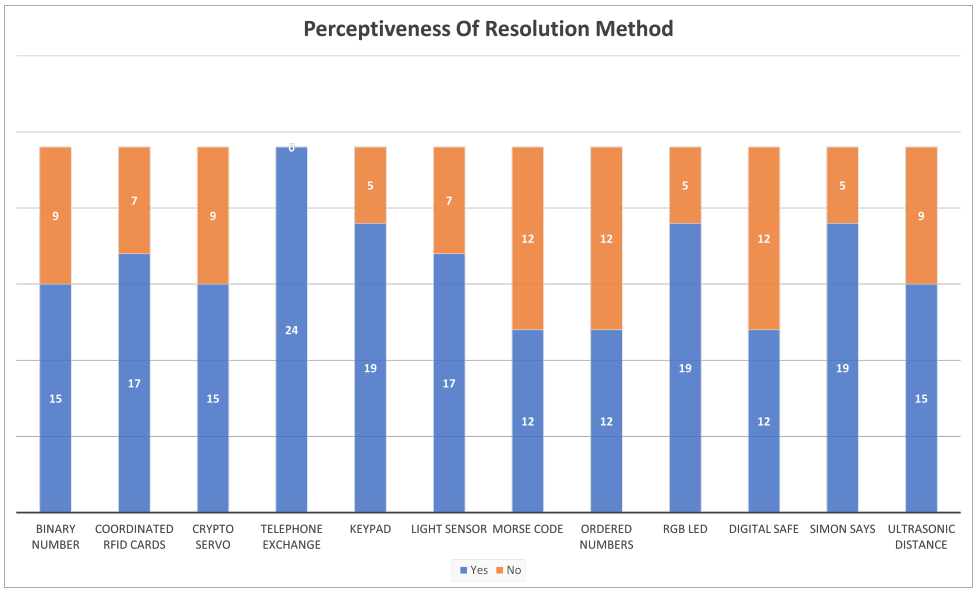


Figure B.1: How well users could perceive how they should interact with the interaction in order to solve it

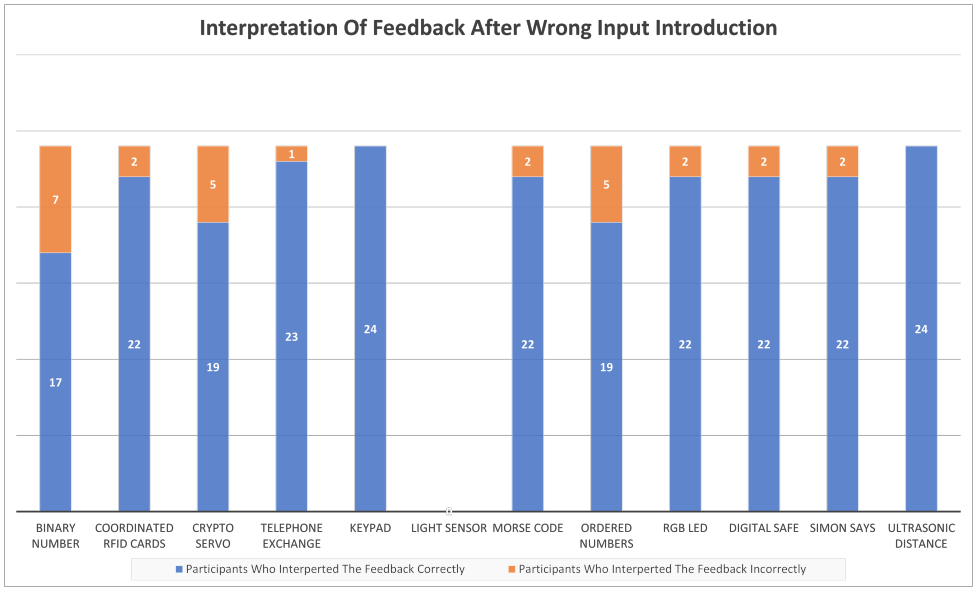


Figure B.2: How well people could perceive that the interaction, upon the introduction of a wrong input, was saying that said input is wrong

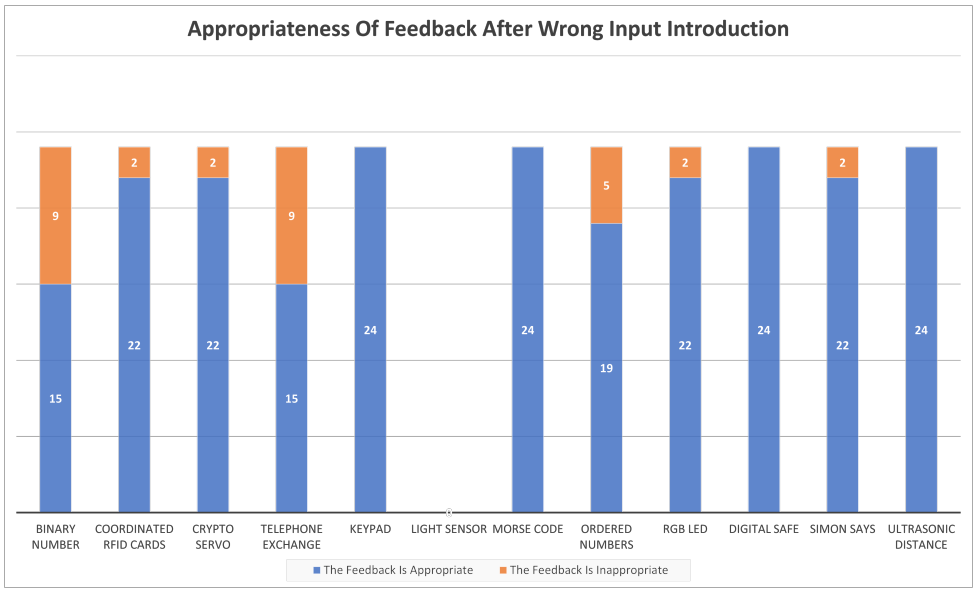


Figure B.3: How appropriate users found the feedback returned by the interaction to be

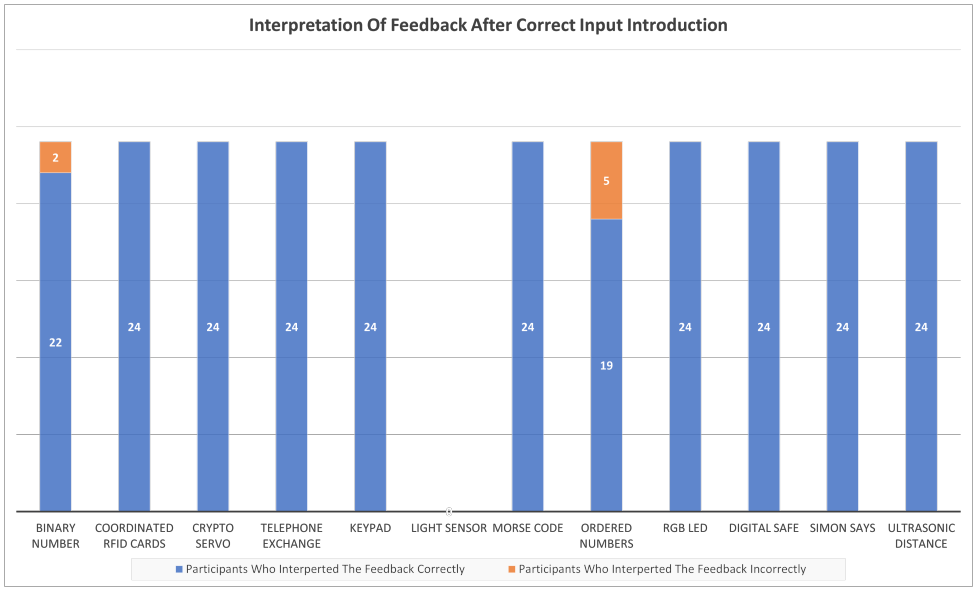


Figure B.4: How well people could perceive that the interaction, upon the introduction of the correct input, was saying that said input is correct

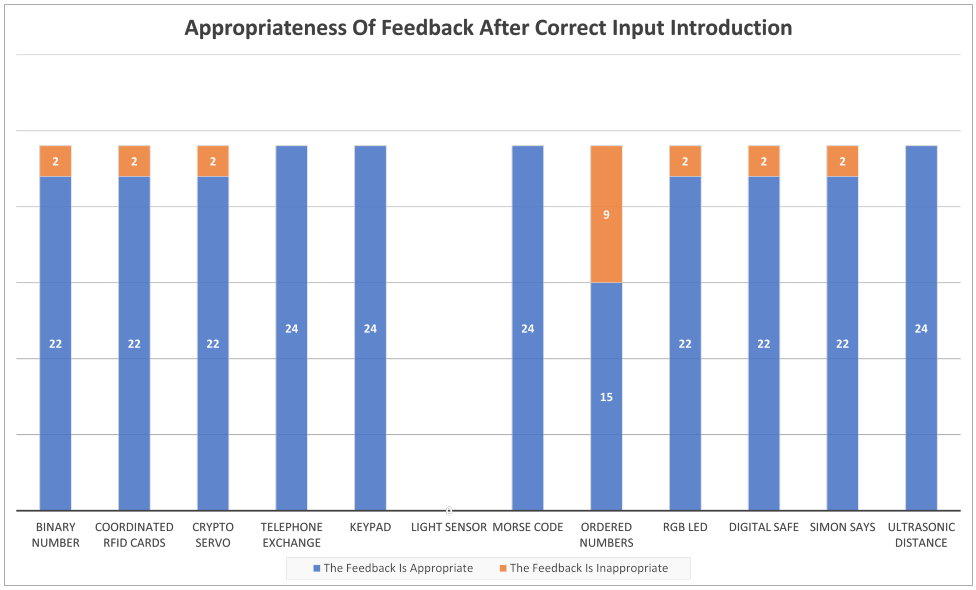


Figure B.5: How appropriate users found the feedback returned by the interaction to be

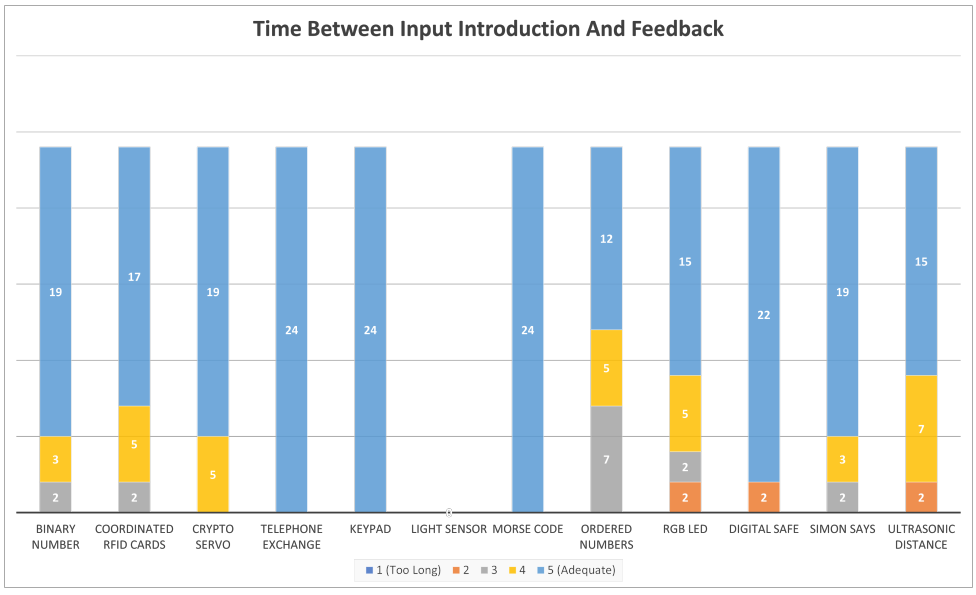


Figure B.6: The time taken between the introduction of an input and the feedback returned by the interaction

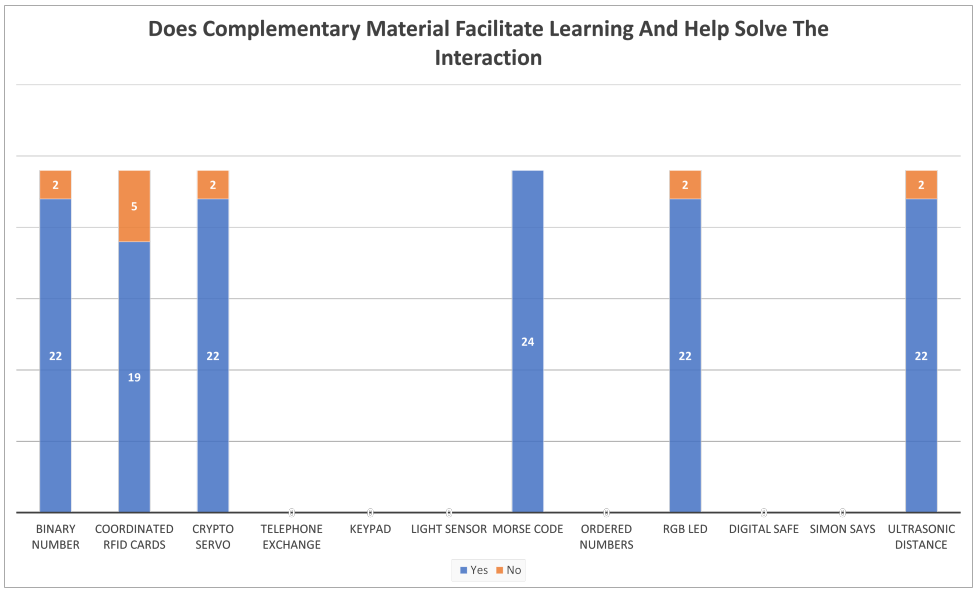


Figure B.7: Whether or not users felt that complementary material helped them understand and solve the interactions

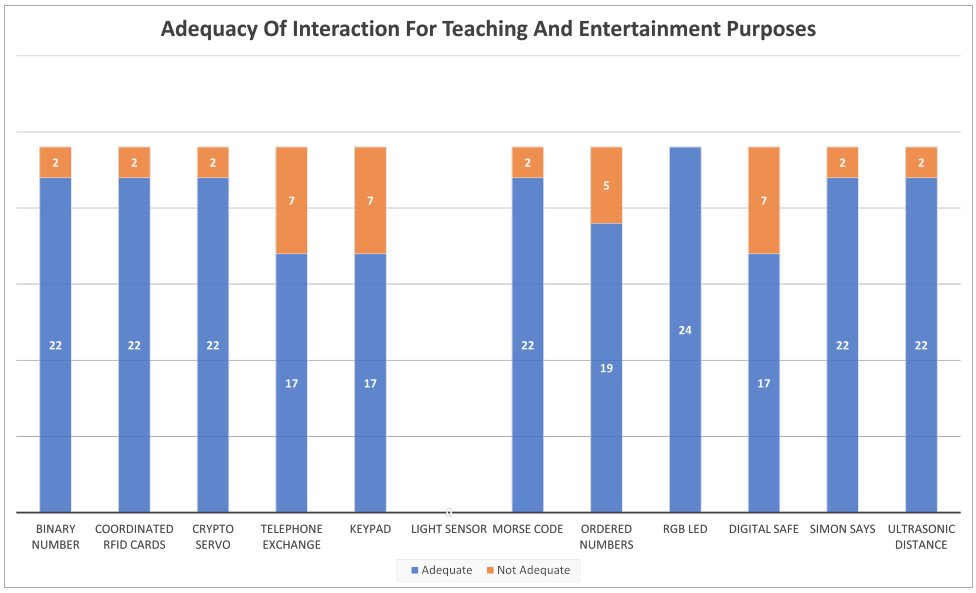


Figure B.8: How adequate did users find the interactions to be for teaching and entertainment purposes

C

Interaction's Form

Interaction's Feedback

This form was made for you to answer questions about each of the interactions you are going to come in contact with. Throughout this form you will find questions that are all very similar from interaction to interaction and we ask you to answer them to the best of your ability.

We also would like to take this opportunity to thank you so much for your contribution for the development of this master thesis, and for taking the time to answer these questions.

The overall time needed to answer this form is around one and a half hours. We sincerely apologise for the longevity of this form and thank you in advance for taking some of your precious time to answer the questions.

*Obrigatório

1. Age *

2. Academic Degree *

Marcar apenas uma oval.

- Primary Education
- Lower Secondary Education
- Upper Secondary Education
- Bachelor's Degree
- Master's Degree
- Doctoral Degree

3. Did You Ever Study Computer Science or Any Directly Related Engineering Subject? (Electronics, Informatics, Telecommunications, etc...) *

Marcar apenas uma oval.

- Yes
- No

4. How would you classify your knowledge in the subjects of Informatics and Electronics *

Marcar apenas uma oval.

	1	2	3	4	5	
Little to No Knowledge	◯	◯	◯	◯	◯	Educated on the Subject(s)

The Interactions

What is asked is that you answer to each of the questions regarding each interaction that is seen in the videos **while imagining that you are playing/interacting with them inside a computation museum**.

If you don't know what a computation museum is or would like to have some insights on what subjects are showcased and learned there you can see some examples in the following links:
- https://www.tnmoc.org/
- https://computerhistory.org/
- https://www.museumofcomputing.org.uk/
- http://www.computinghistory.org.uk/
- https://nexoncomputermuseum.org/english/

The questions will be mainly focused on understanding whether the interactions provide clear feedback to the user regarding the introduced input (if it was a correct attempt or an incorrect one) and on other aspects such as the aesthetics of the interaction, how well does it showcase the theoretical/practical concepts it is trying to teach among other relevant things.

Please do not be afraid to ask questions at any point and please do not, under any circumstance, feel bad if you are unable to solve an interaction or understand it, this form is not to test the subject answering but the interactions themselves.

Interaction #1

Remember These Interactions Are Being Played in a Museum Context

5. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

6. In case your previous answer was 'No', please explain.

7. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

8. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

9. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

10. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=EyOy6EcBeo4

11. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefore nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

12. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

Input 2

http://youtube.com/watch?v=jUtbf_sCXao

13. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

14. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

15. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

16. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

17. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

18. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

19. [Optional] Could you please explain your previous answer?

20. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

21. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

22. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

23. [Optional] How would you improve this interaction?

Interaction #2

Remember These Interactions Are Being Played in a Museum Context

24. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

25. In case your previous answer was 'No', please explain.

26. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

27. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

28. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- ◯ Ruin my Experience.
- ◯ Enhance my Experience.
- ◯ Neither.

29. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=HQvNycz94aI

30. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefor nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

31. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

Input 2

http://youtube.com/watch?v=207t_31DTSA

32. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefor nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

33. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

34. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

35. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

36. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

37. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

38. [Optional] Could you please explain your previous answer?

39. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

40. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

41. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

42. [Optional] How would you improve this interaction?

Interaction #3

Remember These Interactions Are Being Played in a Museum Context

43. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *
Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

44. In case your previous answer was 'No', please explain.

45. Without any additional information, can you determine how this interaction is supposed to be solved? *
Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

46. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

47. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

48. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=2RXOKecsYnI

49. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

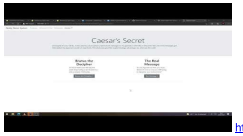
- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

50. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

Input 2



http://youtube.com/watch?v=j93XA8ESDDg

51. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

52. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

53. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable						Very Enjoyable

54. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long						Very Adequate

55. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

56. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

57. [Optional] Could you please explain your previous answer?

58. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy						Very Hard

59. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience						Amazing Experience

60. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

61. [Optional] How would you improve this interaction?

Interaction #4

Remember These Interactions Are Being Played in a Museum Context

62. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *
Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

63. In case your previous answer was 'No', please explain.

64. Without any additional information, can you determine how this interaction is supposed to be solved? *
Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

65. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

66. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

67. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=hgkVJ3LbywY

68. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

69. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

Input 2

http://youtube.com/watch?v=xadSBsDJxJ8

70. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

71. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

72. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

73. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

74. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

75. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

76. [Optional] Could you please explain your previous answer?

77. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

78. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

79. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

80. [Optional] How would you improve this interaction?

Interaction #5

Remember These Interactions Are Being Played in a Museum Context

81. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *
Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

82. In case your previous answer was 'No', please explain.

83. Without any additional information, can you determine how this interaction is supposed to be solved? *
Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

84. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

85. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

86. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=fXn4_oaRmI8

87. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

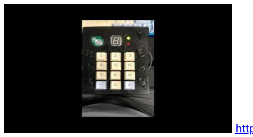
- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

88. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

Input 2



http://youtube.com/watch?v=_0J0JP8CJ10

89. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

90. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

91. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

92. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

93. Do you think the inclusion of complemenary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

94. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

95. [Optional] Could you please explain your previous answer?

96. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

97. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

98. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

99. [Optional] How would you improve this interaction?

Interaction #6

Remember These Interactions Are Being Played in a Museum Context

100. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

101. In case your previous answer was 'No', please explain.

102. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

103. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

104. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

105. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=0cwn8YW-IIY

106. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefore nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

107. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

Input 2

http://youtube.com/watch?v=Csg2390KFU8

108. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefor nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

109. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

110. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

111. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

112. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

113. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

114. [Optional] Could you please explain your previous answer?

115. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

116. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

117. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

118. [Optional] How would you improve this interaction?

Interaction #7

Remember These Interactions Are Being Played in a Museum Context

119. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

120. In case your previous answer was 'No', please explain.

121. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

122. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

123. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- ◯ Ruin my Experience.
- ◯ Enhance my Experience.
- ◯ Neither.

124. Could you explain your previous answer? *

125. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

126. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

127. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

128. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

129. [Optional] Could you please explain your previous answer?

130. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy						Very Hard

131. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience						Amazing Experience

132. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

133. [Optional] How would you improve this interaction?

Interaction #8

Remember These Interactions Are Being Played in a Museum Context

134. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

135. In case your previous answer was 'No', please explain.

136. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

137. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

138. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

139. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=lld1HjVD_Ho

140. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefore nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

141. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

Input 2

http://youtube.com/watch?v=mWxcVu-Xp6E

142. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

143. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

144. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable						Very Enjoyable

145. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long						Very Adequate

146. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

147. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

148. [Optional] Could you please explain your previous answer?

149. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

150. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

151. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

152. [Optional] How would you improve this interaction?

Interaction #9

Remember These Interactions Are Being Played in a Museum Context

153. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

154. In case your previous answer was 'No', please explain.

155. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

156. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

157. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- ◯ Ruin my Experience.
- ◯ Enhance my Experience.
- ◯ Neither.

158. Could you explain your previous answer? *

Input 1

http://youtube.com/watch?v=XyeyPE2FjBU

159. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefore nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

160. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

Input 2

http://youtube.com/watch?v=KzCkebMAcQY

161. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefor nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

162. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

163. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

164. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

165. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

166. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

167. [Optional] Could you please explain your previous answer?

168. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

169. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

170. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

171. [Optional] How would you improve this interaction?

Interaction #10

Remember These Interactions Are Being Played in a Museum Context

172. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

173. In case your previous answer was 'No', please explain.

174. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

175. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

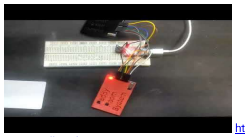
176. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- ◯ Ruin my Experience.
- ◯ Enhance my Experience.
- ◯ Neither.

177. Could you explain your previous answer? *

Input 1



http://youtube.com/watch?v=sIpw3dbB9tk

178. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

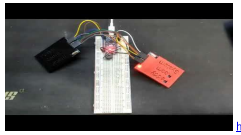
- ◯ The input that was introduced is not correct and therefor nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

179. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

Input 2



http://youtube.com/watch?v=KWJR6Cnv64w

180. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

- ◯ The input that was introduced is not correct and therefor nothing happened.
- ◯ The introduced input was correct and the user managed to solve the interaction.
- ◯ There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- ◯ A failure occurred and there was no feedback given to the user.

181. Assuming the introduced input is **correct**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

182. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

183. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

184. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

185. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

186. [Optional] Could you please explain your previous answer?

187. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

188. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

189. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

190. [Optional] How would you improve this interaction?

Interaction #11

Remember These Interactions Are Being Played in a Museum Context

191. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

192. In case your previous answer was 'No', please explain.

193. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

194. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

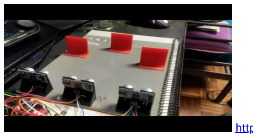
195. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

196. Could you explain your previous answer? *

Input 1



http://youtube.com/watch?v=5_Rf6lL0a24

197. After watching the previous video what do you believe happened?

Marcar apenas uma oval.

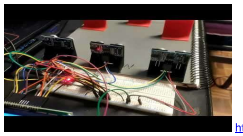
- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure occurred and there was no feedback given to the user.

198. Assuming the introduced input is **wrong**, is the feedback returned by the interaction appropriate?

Marcar apenas uma oval.

- Yes
- No

Input 2



http://youtube.com/watch?v=Y_FtP5M6-Uk

199. After watching the video what was it that happened? (Select what for you is the most correct answer)

Marcar apenas uma oval.

- The input that was introduced is not correct and therefor nothing happened.
- The introduced input was correct and the user managed to solve the interaction.
- There is a lack of additional input (Pressing a button, etc...) preventing the input to be acknowledged by the interaction.
- A failure at the software level occurred and there was no feedback given to the user.
- A failure at the hardware level occurred and there was no feedback given to the user.

200. Assuming that the introduced input is **correct**, is the feedback returned by the interaction enough to understand that it has been solved?

Marcar apenas uma oval.

- Yes
- No

201. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable	◯	◯	◯	◯	◯	Very Enjoyable

202. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long	◯	◯	◯	◯	◯	Very Adequate

203. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

204. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

205. [Optional] Could you please explain your previous answer?

206. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy	◯	◯	◯	◯	◯	Very Hard

207. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience	◯	◯	◯	◯	◯	Amazing Experience

208. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

209. [Optional] How would you improve this interaction?

Interaction #12

Remember These Interactions Are Being Played in a Museum Context

210. Regarding the aesthetics and dimensions of the interaction, would you say it is adequate to be placed in a computation museum? *

Please consider that the interaction, in its final form will have no wires exposed.

Marcar apenas uma oval.

- Yes
- No

211. In case your previous answer was 'No', please explain.

212. Without any additional information, can you determine how this interaction is supposed to be solved? *

Please answer this question only once and after moving to the next questions do not come back to change your answer.

Marcar apenas uma oval.

- Yes
- No

213. [After Solving Interaction] Please take note of the time it took you to solve this interaction *

214. If you were to learn a certain subject with the aid of this interaction do you think that it would ruin or enhance your learning experience? *

Marcar apenas uma oval.

- Ruin my Experience.
- Enhance my Experience.
- Neither.

215. Could you explain your previous answer? *

216. How enjoyable was your learning process when using this interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not Enjoyable						Very Enjoyable

217. How long do you find the time between the introduction of the input and the feedback given by the interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Too long						Very Adequate

218. Do you think the inclusion of complementary material like the one provided to you helps solve the interaction? *

Marcar apenas uma oval.

- Yes
- No

219. Now that you understand the interaction completely, do you find it adequate to be used in a computation museum context for teaching and entertainment purposes? *

Marcar apenas uma oval.

- Yes
- No

220. [Optional] Could you please explain your previous answer?

221. Regarding the difficulty of this interaction, how would you classify it? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Easy						Very Hard

222. Overall how would you rate your experience with this Interaction? *

Marcar apenas uma oval.

	1	2	3	4	5	
Horrible Experience						Amazing Experience

223. [Optional] Here you can describe your experience pointing out positive/negative aspects about it

224. [Optional] How would you improve this interaction?

General Questions

In this section of the form we will ask you some questions in order to understand the effect that the interactions had on you with regards to certain attitudes towards museums and exhibits.

225. Imagine that you had the choice of going to a museum that provides you with audio guides and guided tours or going to a museum that featured these interactions and others of sort. Which one would you rather/would be more inclined to go? *

Marcar apenas uma oval.

- The Museum with Audio Guides and Guided Tours
- The Museum with the Interactions/Interactive Experiences

226. [Optional] Could you justify your previous answer?

227. Given the previously mentioned types of museums (Guided Tours and Audio Guides VS Interactions and Interactive Experiences), to which would you be more inclined in re-visiting? *

Marcar apenas uma oval.

- The Museum with Guided Tours and Audio Guides
- The Museum with Interactions and Interactive Experiences

228. Did you need to download a mobile app on your phone to be able to enjoy any of the interactions? *

Marcar apenas uma oval.

- Yes
- No

229. If your answer to the previous question was 'Yes', how did it affect you experience?

Marcar apenas uma oval.

- Harmed It
- Didn't Affect my Experience

230. You had contact with several Interaction types (Phone, Tangibles, Computer, etc...). How did this diversity affect your experience? *

Marcar apenas uma oval.

- Improved It
- Worsened It
- Had no Effect

231. [Optional] Could you justify your previous answer?

D

Escape The Room Form

Peddy Room System Feedback

This form has the purpose of gathering feedback from the participants of the Escape The Room at the end of the game so that we, the development team, can understand what are the main positive and negative aspects of this solution to the topic of enhancing visitors experience in the museum via the use of an Escape The Room game.

Please point out anything that you find relevant in the appropriate parts of the form and give your most honest and constructive feedback possible.

I would also like to take the time to thank you for answering this form and taking the time to play the Escape The Room game, it means a lot to this work that you have taken some of your precious time to help us in the development and analysis of our solution.

*Obrigatório

Personal Information

This section is for you to introduce some basic information about yourself.

1. Age *

2. Sex *

Marcar apenas uma oval.

- Male
- Female
- Prefer not to say

3. Highest Degree of Education Achieved *

Marcar apenas uma oval.

- Primary Education
- Lower Secondary Education
- Upper Secondary Education
- Bachelor's Degree
- Master's Degree
- Doctoral Degree

4. Did You Ever Study Computer Science or Any Directly Related Engineering Subject as Part of Your Education? (Electronics, Informatics, Telecommunications, etc...) *

Marcar apenas uma oval.

- Yes
- No

5. How would you classify your knowledge in the subjects of Informatics and Electronics?

Marcar apenas uma oval.

	1	2	3	4	5	
Little to No Knowledge	◯	◯	◯	◯	◯	Educated on the Subject

Digital Technology Usage

This section has the purpose of letting us know what is your usage or at the very least familiarity with digital devices (i.e. Cellphones, Computers, Tablets, etc...) and additionally how frequently do you visit museums and what types of experiences have you had in them.

6. Are you a user of Digital Devices? *

Marcar apenas uma oval.

- Yes
- No

7. Do you have a Cellphone, Tablet and/or Computer at home? *

Marcar apenas uma oval.

- Yes
- No

8. How frequently do you use digital devices daily? *

Marcar apenas uma oval.

	1	2	3	4	
Very Few	◯	◯	◯	◯	Very Frequent

9. Which of the following scenarios do you identify the most with? *

Marcar apenas uma oval.

- I use digital devices for work/professional purposes
- I use digital devices for entertainment purposes
- I use digital devices for both entertainment and work purposes

Museums and Digital Devices - Your Opinion

10. What is your opinion towards the usage of digital devices in a museum context? *

Marcar apenas uma oval.

- Neutral
- Positive
- Negative

11. Lets assume that you visit a museum and this museum provides you with an alternative experience for which, for you to enjoy, you have to download an app to your mobile phone. Would you be willing to download that app for the sake of enjoying that alternative experience? *

Marcar apenas uma oval.

- Yes
- No
- Would Rather Not Answer

Thank you and Have Fun Playing!

Thank you very much for your honest answers. Now that we collected some basic information about you, you can now proceed to play the Escape The Room. At the end, you'll have to answer a few more questions regarding the experience.

The Visiting Experience

This section focuses on what you, the visitor of the museum and player of this Escape The Room, felt during the time you played the game. The purpose of this section is to understand what are your feelings towards this type of interaction(s) and their usage in a museum for the purpose of enhancing your visit.

We would like to recall that this Escape The Room has the purpose of integrating digital technologies in the museum so as to enhance the visiting experience or, at the very least, give visitors the choice of using digital means to interact with the museum. While answering the questions that follow please try to picture this Escape The Room integrated into an ongoing exposition where each interaction is accompanied by a relevant piece and details about said piece that give some context to what the interaction is doing and how it can be solved.

12. How would you rate your overall experience? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very Bad	◯	◯	◯	◯	◯	Very Good

13. When compared to a traditional museum visit (Text plates and audio guides) do you find this approach more or less interactive? *

Marcar apenas uma oval.

	1	2	3	4	
Less Interactive	◯	◯	◯	◯	More Interactive

14. If you answered "More Interactive" in the previous question, do you find this bigger degree of interactivity beneficial or harmful for your visiting experience? *

Marcar apenas uma oval.

- Beneficial
- Harmful
- Neutral

15. How did you enjoy each of the interaction types? *

Marcar apenas uma oval por linha.

	Didn't Enjoy Using It	Indifferent	Enjoyed Using It
Tangible Interactions (RFID Cards, Keypads, etc...)	◯	◯	◯
Smartphone	◯	◯	◯
Computer	◯	◯	◯

16. If you didn't enjoy a certain Interaction type do you find that having alternative types made the experience more enjoyable to you? Why?

17. During the Escape The Room you had to make use of your smartphone. At any point did your smartphone lack a feature that prevented you from progressing? *

Marcar apenas uma oval.

- Yes
- No

18. Do you find that the diversity of Interaction Types positively contributes to the experience? *

Marcar apenas uma oval.

- Yes
- No
- Indifferent

Escape The Room

In this section we aim to understand what is your opinion towards several of the elements of the Escape The Room as well as the Escape The Room as a whole.

19. Did you previously tested the interactions individually? *

Marcar apenas uma oval.

- Yes
- No

20. If you answered 'Yes', did you find their usage within the context of the escape the room to be more or less enjoyable than when used individually?

Marcar apenas uma oval.

- ◯ More Enjoyable
- ◯ Less Enjoyable
- ◯ Neither

21. Out of the 12 interactions, which ones did you enjoy the most and enjoyed the least? *

Marcar apenas uma oval por linha.

	1 (Enjoyed The Least)	2	3	4	5	6	7	8
Binary Number	◯	◯	◯	◯	◯	◯	◯	◯
Morse Code	◯	◯	◯	◯	◯	◯	◯	◯
Crypto Servo	◯	◯	◯	◯	◯	◯	◯	◯
Simon Says	◯	◯	◯	◯	◯	◯	◯	◯
Ordered Numbers	◯	◯	◯	◯	◯	◯	◯	◯
Digital Safe	◯	◯	◯	◯	◯	◯	◯	◯
Coordinated RFID Cards	◯	◯	◯	◯	◯	◯	◯	◯
Ultrasonic Distance	◯	◯	◯	◯	◯	◯	◯	◯
RGB LED	◯	◯	◯	◯	◯	◯	◯	◯
Light Sensor	◯	◯	◯	◯	◯	◯	◯	◯
Telephone Exchange	◯	◯	◯	◯	◯	◯	◯	◯
Keypad	◯	◯	◯	◯	◯	◯	◯	◯

22. With regards to difficulty, how would you rate each interaction? *

Marcar apenas uma oval por linha.

	1 (Very Easy)	2	3 (Average)	4	5 (Very Hard)
Binary Number	◯	◯	◯	◯	◯
Morse Code	◯	◯	◯	◯	◯
Crypto Servo	◯	◯	◯	◯	◯
Simon Says	◯	◯	◯	◯	◯
Ordered Numbers	◯	◯	◯	◯	◯
Coordinated RFID Cards	◯	◯	◯	◯	◯
Keypad	◯	◯	◯	◯	◯
Light Sensor	◯	◯	◯	◯	◯
Telephone Exchange	◯	◯	◯	◯	◯
Digital Safe	◯	◯	◯	◯	◯
RGB LED	◯	◯	◯	◯	◯
Ultrasonic Distance	◯	◯	◯	◯	◯

23. After having played the game, do you feel motivated to return to replay it and revisit the museum?

Marcar apenas uma oval.

- ◯ Yes
- ◯ No
- ◯ Maybe

24. Which kind of museum would you feel more motivated in revisiting?

Marcar apenas uma oval.

- ◯ Traditional Museum
- ◯ Museum Featuring the Interactions and Escape The Room you Just Played

25. Open Feedback about your experience