Exploring the Impact of an IoT-based Game on the Experience of Visitors at a Natural Science Museum

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The use of Internet of Things (IoT) technology to improve access to cultural heritage sites and enhance visitor engagement has become increasingly popular. Nevertheless, there is a lack of studies evaluating the actual benefits of such technology for visitors' experiences, which is a crucial aspect to improve its adoption in this field. To address this issue, we present an explorative study we performed to understand whether and how an IoT-based game affects the experience of museum visitors. The game is played after a traditional guided tour; it was created following a meta-design approach to enable domain experts, such as museum professional guides, to adapt the game to specific visitors and/or situations. The study involved a total of 18 participants who took a guided tour of the Museum of Natural Sciences of the University of Bari and played the game afterward. Both quantitative and qualitative data were collected. The study results show that playing an IoT-based game positively affects the experience of visitors and, in particular, their emotions. Visitor workload was also found to be higher than that of a guided tour, but this had no negative impact on visitor experience. The study findings have implications for the design and development of future IoT games to enhance engagement and to improve the experience of visitors at cultural heritage sites.

CCS CONCEPTS • **Human-centered computing → User studies; •Applied computing → Arts and humanities**

Additional Keywords and Phrases: Exploratory study, User experience, Emotions, Workload

ACM Reference Format:

Fabrizio Balducci, Paolo Buono, Giuseppe Desolda, Rosa Lanzilotti, Antonio Piccinno, and Maria Costabile. 2023. on Museum Visitors' Experiences. ACM Journal on Computing and Cultural Heritage, Vol. N, No. M, Article L. Publication date:??????.

1 INTRODUCTION AND BACKGROUND

It is increasingly recognized that cultural heritage (CH) must be valued as a legacy from the past to share with present and future generations to help build cultural identities [1, 2]. Various research works have shown that advanced information and communication technologies can help increase awareness and appreciation of CH content among various audiences [3-7]. The Internet of Things (IoT) has emerged as a promising technology for improving access to CH collections. IoT systems use distributed software services that provide access to functionality and data through physical devices over the Internet. These devices, known as smart objects [8], typically have sensors to detect events occurring in the observed environment and/or actuators to perform actions that change the state of the environment or the IoT system.

The IoT can revolutionize how people visit CH sites and interact with their collections. Several studies recognize the benefits of physical manipulation and action as additional channels for conveying information since they activate real-world knowledge and improve memory [9, 10]. Smart objects and IoT-based systems can increase visitor engagement and create personalized, immersive experiences that promote a deeper understanding of CH content [11-13]. One of the most important benefits of IoT technology in CH is its ability to connect physical objects to the digital world in an ecological way, since it does not require the installation of any intrusive technological infrastructures, thus preserving the environment and saving money. By embedding sensors and other data-collecting devices into tangible artifacts, IoT systems can capture real-time information about visitors' interactions with CH objects, enabling the creation of customized narratives and experiences based on visitors' interests, preferences, and prior knowledge. In addition, IoT technology can enable the creation of smart environments at CH sites where visitors can interact with various objects, exhibits, and installations in novel and engaging ways. For example, visitors can use IoT-enabled devices to scan QR codes or RFID tags on CH objects, triggering digital content such as images, videos, or audio recordings that provide additional information and context.

Despite the interest in IoT-enabled solutions for CH sites and collections, little research has been conducted to examine the impact of IoT technology on visitors at CH sites. Human-computer interaction researchers refer to User eXperience (UX) to indicate the overall experience people have when interacting with information technology (IT). The definition provided by the ISO standard for UX is "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service. UX is actually a complex concept that includes subjective attributes such as aesthetics, emotions, and social involvement. Traditionally, IT applications were concerned mainly with ease of use: a primary goal of product and service design was to provide useful and usable functionality to support people in performing their tasks. These goals are still important, but the abundance of goods and services now available demands that they also be pleasurable [14]. UX is still a broadly defined term that includes satisfaction of noninstrumental needs (e.g., aesthetic, hedonic, creative, and social) and the acquisition of positive feelings and well-being; the emotions aroused in the user are especially relevant.

Because of the great potential of IoT technology to enhance engagement and create personalized experiences in several contexts, including CH, it is interesting to investigate its impact on the UX of people who interact with IoT technology when visiting CH sites. The novel contribution of the research work presented in this article is that it sheds light on the strengths and weaknesses of IoT-based games and the factors that contribute either positively or negatively to the UX of visitors to CH sites. The lessons learned inform the design and development of future IoT solutions that focus on creating experiences tailored to visitors' needs, preferences, and prior knowledge.

The IoT-based game (or IoT game for short) considered in this article is called *Magic Torch*; it was created to be played by museum visitors after a guided tour, serving as a debriefing phase aimed at consolidating the knowledge acquired during the tour, as suggested in [15, 16]. In teams of two, the visitors use a smart torch and a deck of smart cards to solve riddles about cultural artifacts exhibited in the museum. Magic Torch was designed according to the meta-design approach described in [17] to allow museum curators and professional guides to adapt the game to specific visitors and situational needs by modifying the behaviors of the smart objects involved in the game. This article reports an explorative study conducted to elucidate the factors that influence the UX of people playing an IoT-based game. We recruited 18 young visitors and asked them to participate in a study organized in two parts: first, participants took part in a guided tour of the Museum of Natural Sciences of the University of Bari; afterward, they played the Magic Torch game, freely moving in the museum according to the game indications. We measured visitors' emotions and other aspects of their overall experience, as well as their workload during both the guided tour and the game. We also carried out a qualitative analysis of the participants' behaviors during the game. As we said, UX refers to the experience of a person during the use of an IT product, system or service; since in our study we analyze the experience of visitors playing the IoT-based game as well as the experience of visitors performing the guided tour without the use of technology, we use the term *visitor experience* in the rest of this article. The study results show that emotions are positively affected by the use of IoT technology since pleasure, arousal, and dominance are greater when visitors play the Magic Torch game. Similarly, visitor experience is better when playing the IoT game, particularly because of the hedonic aspect of the visitor experience. We also found that workload is greater, but this does not negatively affect the emotions and overall experience of the visitor. These results are discussed, and implications and contributions are reported; the results may support the design and development of IoT games that can increase engagement and improve the overall experience of visitors at CH sites.

This article is organized as follows. Section 2 presents related works about IoT applications in CH, with the aim of addressing primarily those works that have considered the impact on visitor experience. Section 3 presents the Magic Torch game: first, it describes how the game is played; second, the meta-design approach to creating the game with domain experts, namely, the professional guides of the Museum of Natural Sciences of the University of Bari, is illustrated; and, finally, the technical implementation of the game smart objects is described. Section 4 reports the exploratory study conducted with 18 visitors and 1 professional guide, while Section 5 discusses its results, underlining the lessons learned. Section 6 addresses the study limitations, and Section 7 concludes the article by outlining future work.

2 RELATED WORK

Modern museums, as well as other valuable CH sites, try to enhance visitors' experiences through digital technology, ranging from computer displays to smart technology, with the aim of attracting a wider audience and actively involving visitors [18]. Thus, museums are shifting their role and structure from just a repository of artifacts to active edutainment venues supported by digital innovation [19].

Unfortunately, IT technologies often fail to be adopted in CH contexts due to barriers to digital innovation within CH organizations. Some authors have categorized three major barriers (see e.g. [20] [21] [tham liu loo]): 1) little appetite for digital innovation; 2) technical barriers, e.g., insufficient infrastructure; and 3) financial barriers, e.g., limited time and resources to manage digital innovation . For example, in Italy, there are more than 4000 public museums[1], but most of them cannot enrich their exhibitions with advanced and expensive technologies, such as interactive screens [22] or holographic projections [23], due to a lack of economic resources and the difficulties in maintaining such installations. IoT technology is also appealing because it is inexpensive and ecological, i.e., it does not require any intrusive external devices to be installed.

To engage people during visits to CH sites, some systems propose games to be played in groups, especially when the systems are targeted at very young visitors, e.g., schoolchildren, who account for a significant percentage of the visitors at many sites (e.g., see [24-26]). Gamification is a very popular term and refers to the use of game elements in various contexts and computer applications; it is a process that consists of using game logic and its mechanics to better involve users and solve real problems [Zichermann 2013]. A gamification approach can also introduce a rewarding factor in the decision-making process so that users are encouraged to carry out the tasks they need to perform; in other words, the game makes performing specific tasks more fun. Therefore, the focus on game development continues to increase also in the CH domain (see, e.g., [Anderson *et al*. 2010], [Mortara *et al*. 2014][riff nostri su Explore! che servono e altri giochi nostri]). In some cases, they are serious games that have some didactic goals; in other cases, they are just "playful games" [Origlia *et al*. 2016], whose aim is to stimulate people's curiosity to attract them to CH and to enjoy, so that the visitor experience could be improved. Many authors have highlighted the positive educational aspects of games [27-30]. Gameplay is often a relational activity: it encourages group activities, stimulates collaboration, and requires various skills to be deployed simultaneously, and each player can practice those skills felt to be the most congenial. Moreover, enjoyment directly affects motivation, which is important when individuals are endeavoring to achieve learning goals [31]. The games designed to be played at CH sites are often organized as a treasure hunt, which requires players to explore the environment to identify meaningful places and artifacts, which are the targets of the tasks they must perform. This type of game is ideal in contexts such as a museum or an archaeological park, where there are large areas visitors can move through freely, observe artifacts on display or analyze archaeological ruins, and use their intelligence and imagination to envisage how the original artifact was used or what might have been in place of the few remains. An example of a treasure hunt game to be played on mobile devices that exploits the IoT is "À la recherche de l'empreinte perdue" (Seeking the lost footprint); this game allows players to uncover the cultural heritage of the city of Saint-Jean-Brévelay, France, by solving puzzles and following clues [32]. The Magic Torch game described in this article is also an IoT-based treasure hunt game to be played when visiting a museum.

Another reason why IoT technology is appealing at CH sites is because smart objects promote engagement and appropriation [10, 11]. Such benefits are in part determined by tangible interaction with objects; for example, [33] reports that after visiting the archaeology section of a museum, children were provided with boxes useful for simulating, in a tangible form, the archaeological "dig" process, and the children very much enjoyed this. In

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[1] https://www.istat.it/it/archivio/musei

the literature, there are proposals of systems to support visits to CH sites, allowing for tangible interaction with smart objects. (e.g., see [34]). Notable contributions resulted from the meSch project (see, e.g., [11, 35]), whose overall goal was to support CH professionals in creating and deploying personalized interactive experiences that allow visitors to manipulate smart tangible objects. An interesting case study developed within the *meSch* project is Loupe: based on the use of a smart object, called *magnifying glass*, a museum visitor can point to specific objects to obtain various details of the CH content in augmented reality. Another case study of meSch concerns the use of the *interactive belt*, which a visitor can wear while trekking on the Italian Alps to visit what remains of the World War I Italian trenches. When the visitor enters an area where there are artifacts of interest, the belt detects the closest one and emits a sound that attracts visitors to the artifact; if the visitor moves closer, the belt speaker plays the story of the artifact. The use of smart objects in the case studies of meSch is in line with other proposals, such as: museum visits featuring activities performed through an old military torch with IoT capabilities [36]; a location-based treasure hunt game in which students find treasures while learning historical and cultural content [37], a treasure hunt game in which players interact with smart cards while exploring a site [MANCA UN RIFERIMENTO]. These games inspired our Magic Torch.

An interesting proposal for enabling CH experts to manage IoT technology was proposed in [38]; the authors described a rapid prototyping toolkit based on a visual interaction paradigm to support CH experts and designers in collaborating and cocreating valuable interactive visit experiences at CH sites. Experts create the VE in two phases: the first is a more conceptual phase that consists of using physical materials such as paper, sticky notes and cards to ideate cross-reality experiences; in the second phase, the experts use a digital tool called *MyXRGames* to prototype ideas. A usability evaluation of the toolkit was reported, but the participants' emotions were not analyzed. Supporting the ideation of IoT applications is also the objective of the paper reported in [39]; the authors propose a card-based IoT game ideation tool for the museum context to help teams of designers, even nonexperts, achieve idea generation. Specifically, the tool, consisting of 90 cards for idea generation, aims to help individuals acquire understanding of domain-specific design knowledge and to support initial and more in-depth development of ideas.

The work presented in [40] concerns the evaluation of visitor experience; it first describes a game called *H-Treasure Hunt*, which integrates location-based services to find the location of augmented artifacts at historic sites. The participants' experience was evaluated using a questionnaire created by the authors; this questionnaire included 13 items scored on a 5-point Likert-type scale; most items, rather than focusing on different emotions, addressed the practical benefits of the game and the ease of use of the interface. In our study, we evaluated visitors' emotions using the SAM questionnaire [41], which is widely used and has been validated in several studies published in the literature.

A recent publication reports a literature review addressing how technology and digital innovations are transforming museums [Tham, Liu, Loo 2023]. The review focuses on the processes of museum digital innovations, the challenges museums face, and the avenues for future research. Several technologies adopted in museums are mentioned, including augmented/virtual/mixed reality technologies and IoT. However, there is not any indication on studies that investigate the actual impact of such technologies on the experience of museum visitors, it is only generally reported that current advanced technologies are adopted to improve the visitor experience.

3. MAGIC TORCH: AN IOT-BASED GAME FOR A MUSEUM

The IoT-based game we created is called *Magic Torch*. This game has been presented previously [42]. This section describes the design and development of the game. First, how a group of visitors plays the game is explained. The meta-design of the game is illustrated, and this approach was adopted because we aimed to enable CH experts to adapt the game to specific situational needs. Finally, some technical details of the smart objects used in *Magic Torch* are reported.

Because of the mentioned affinity between the environment of cultural sites, which are full of objects and stories to discover, and a treasure hunt that involves imaginary adventurous explorations of unknown environments, the *Magic Torch* game is organized as a treasure hunt to involve and immerse visitors in an interactive experience of discovery.

3.1 Playing the game

Magic Torch was designed to be played at the end of a guided museum visit for visitors to reflect on what they learned during the tour [15, 16]. The current implementation is a game for the Natural Science Museum located on the campus of the University of Bari, Italy. Most museum visitors are young people, primarily students aged between 9 and 30 years.

At the end of the traditional guided tour of the museum, visitors are invited to play the *Magic Torch* game. The museum guide first divides the visitors into small teams (in our study, we had teams of 2 participants) and gives each team a *Magic Torch* device and a deck of 7 cards, each containing a riddle, namely, a description of an artifact that the team has to identify based on the information the guide provided during the tour. By solving these riddles, the team identifies the secret key needed to open a treasure box, which provides a prize to the players.

At the start of the game, the team randomly selected one of the 7 cards and placed it near the torch so that the torch 'understood' the artifact to be found via the RFID integrated inside the card. The team explored the museum, looking for artifacts that solved the card riddle. Once the players have identified the artifact that they believe correctly matches the riddle, they place the torch close to it, specifically, near a small label, so that the torch recognizes the artifact through the label RFID tag. If the artifact is correctly identified, the torch flame turns green, a sound indicates that the answer is correct, and one of the secret key symbols appears on the display. If the players incorrectly identify the artifact, the torch glows red and emits a different sound; the players then look for another artifact to solve the riddle. When all the riddles are solved and the secret key is complete, the team reaches the treasure box, enters the secret code to open it, and receives the prize.

3.2 The meta-design of the game

Despite the advantages of the IoT, there are still important issues to be solved to increase its practical impact. Research has focused mainly on technical features, for example, how to program sensor and actuator networks and how to ensure their interoperability [43, 44]. The opportunities offered by the IoT can be significantly amplified if new approaches are conceived to enable nontechnical users to modify the behavior of smart objects themselves. Programming the behavior of smart objects is still an opportunity for professional developers; it requires the use of scripting languages unfamiliar to nontechnical users, which can also vary depending on the hardware used. Often, the available smart objects expose a very specific functionality that does not result in useful services that are able to accommodate users' needs. Very few approaches attempt to facilitate the configuration of smart objects, and their benefit is limited to programming individual objects that people carry with them during visits to a CH site to receive personalized content when they reach certain interactive points in the exhibit (see, e.g., [11]). It is still difficult for CH experts, such as site curators and professional guides, to program multiple devices to provide visitors with new experiences, determined by various sensors and actuators either installed in the environment or embedded in tangible objects manipulated by visitors who are capable of actively reacting to specific detected events.

Desolda *et al*. proposed a visual composition paradigm that allows nontechnical end users to modify the behavior of multiple smart devices [45]. Indeed, end users possess the domain knowledge required to build applications that can support their tasks; they are the most suitable stakeholders for specifying how the available resources should be exploited to create new valuable services. Several end-user development (EUD) methods have been proposed to help users shape their systems to support personal and situational needs (see, e.g., [46-50]). The EUD paradigm defined by Desolda *et al*. provides nontechnical users with visual mechanisms that allow them to modify the behaviors of smart objects by defining *event-condition-action* (ECA) rules that combine multiple events and conditions exposed by smart objects, also defining temporal and spatial constraints on rule activation. In our research work, we adopted such a paradigm to enable cultural site experts to modify the behavior of smart objects.

The EUC is determined by the need to actively involve end users in overall software design, development, and evolution processes to cocreate systems more appropriate for their needs. Tasks traditionally performed by professional software developers are transferred to end users, who must be properly supported in the new roles of designers and developers. To create applications that allow end users to develop and modify software artifacts and, in the case of the IoT, to modify the behavior of smart objects, a two-phase design process must be implemented: the first phase (meta-design phase) consists of designing the design environments and the tools suited to the stakeholders who participate in the design of the final application; the second phase consists of designing the final application, using the design environments and tools developed in the first phase. This two-phase process is called meta-design, which literally refers to design for designers [48, 51]; it allows various stakeholders to act as codesigners. In other words, professional designers and developers do not create the final application, as in traditional design, but create software environments through which various stakeholders can contribute to the design of the final application. Meta-design permits accounting for multiple perspectives from different stakeholders, including IT experts, who have the specific technical knowledge to create computer systems but do not know the problem domain well, and domain experts and end users, who know the problem domain but do not know about system design and development [52].

It is worth remarking that, in many contexts and particularly when dealing with smart objects, another phase must be added to the previous two phases. In the case of the *Magic Torch* game, a third phase might be needed once the final game is created because domain experts can still modify the behavior of the involved smart objects to adapt the game to situational needs. Specifically, we will describe how the meta-design of the *Magic Torch* game was performed with the involvement of professional guides. The meta-design of the game is sketched in Figure 1: the three phases are represented by the three layers. The top layer involves only IT experts, who use hardware and software components to create the environment and tools to be used in the next phase to design the *Magic Torch* game. The hardware components are IoT boards, sensors, and actuators. The software components include programming environments, such as the Arduino IDE, which includes those for programming smart objects. The middle layer benefits from the collaboration between IT experts and domain experts (professional guides for the *Magic Torch* game), who create the *Magic Torch* game using the environments and tools created in the previous meta-design phase. They also create a specific configuration of an EUD platform, EFESTO-5 W, which provides the visual paradigm for the customization of the smart object behaviors mentioned above [45]; thus, the EFESTO-5 W platform enables domain experts to perform EUD activities that permit adapting the *Magic Torch* game to specific visitors and situational needs.

During the meta-design of the game, we carried out several workshops involving three experts working at the Museum of Natural Sciences at the University of Bari who had organized several guided tours of the museum. In the first workshop, the general idea was conceived. According to the CH experts' experiences and our skills in educational games, we decided to create an IoT game in the form of a treasure hunt to be played after a guided museum tour because we did not want to create technology that completely replaces the visit with professional guides [53, 54]; instead, we used technology to make the entire experience more engaging and effective. Considering the most frequent audience of the museum, we decided to target the IoT application to young people aged between 18 and 30. The workshop provided the general idea of the game, which is actually very similar to the final design reported in Section 3.1.

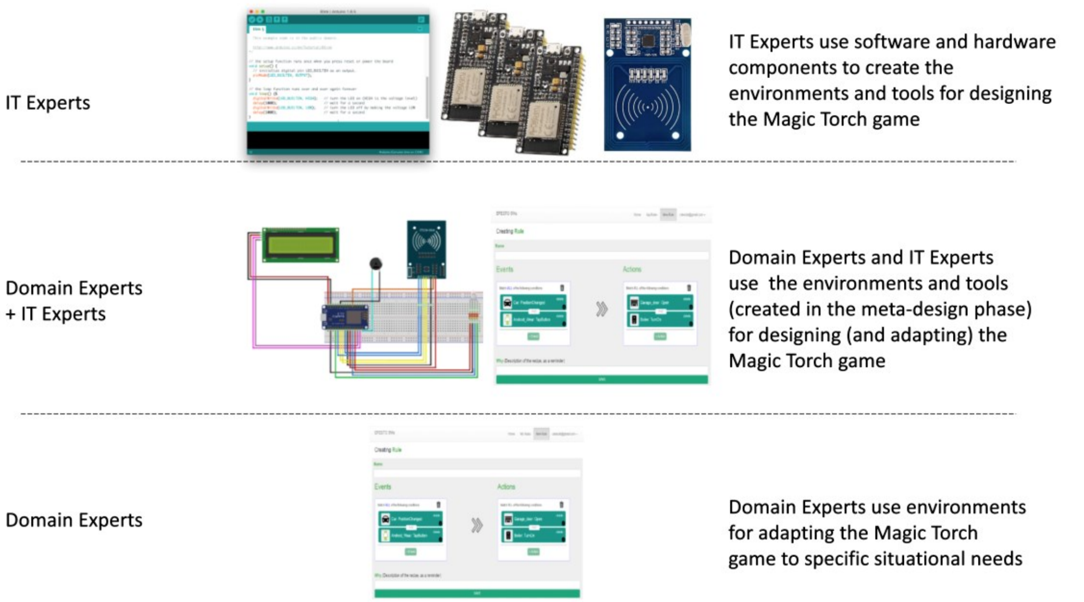


Figure 1. The meta-design approach followed to create the Magic Torch game. For each layer, the stakeholders performing the (meta-)design activities are indicated on the left, while what is used to perform such activities is on the right.

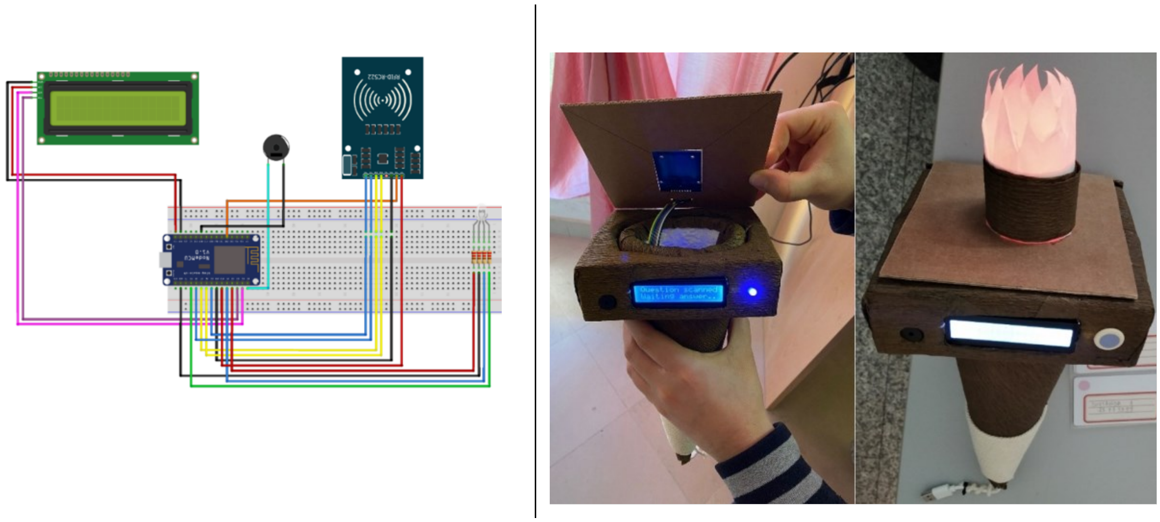
After this workshop, two IT experts performed the meta-design activities mentioned in the top layer of Figure 1. Then, other workshops were held with the CH experts to perform the activities in the second layer; in particular, they created an initial prototype of the smart torch, a set of smart cards, and a treasure box. Formative evaluations of prototypes at different levels of fidelity were performed using informal tests with CH experts to develop a game that satisfied the users' expectations. A configuration of the EFESTO-5 W platform for the *Magic Torch* game was also created on a remote web server; the CH experts used this configuration to create an initial set of ECA rules that define the smart objects' behaviors. Some examples are (reported in a simplified way for the sake of clarity) as follows:

- IF the torch reads a question card THEN set the state of the torch to "waiting for an answer".
- IF, the torch is set to "waiting for an answer" AND the torch reads an answer AND the answer is the right one. THEN displays the green flame AND plays the "correct answer" sound AND shows the next secret key symbol on the display.

The three CH experts spent approximately one month defining and refining the ECA rules, all the content of the guided visits, and the riddles of the IoT game. The IT experts implemented the final version of the smart objects needed for the game, namely, *Magic Torch*, the treasure box, 6 groups of 7 smart cards with the riddle for the visitors to solve, and 49 answer cards, 7 for the right answers and the remaining ones for the wrong answers. The 7 cards with the correct answers are positioned near the museum artifacts corresponding to the correct answers to the riddles, and the other 42 cards are positioned near artifacts that are wrong answers to the riddles. In subsequent sections, we provide technical details of the smart objects involved in the *Magic Torch* game.

3.3 The implementation of Magic Torch

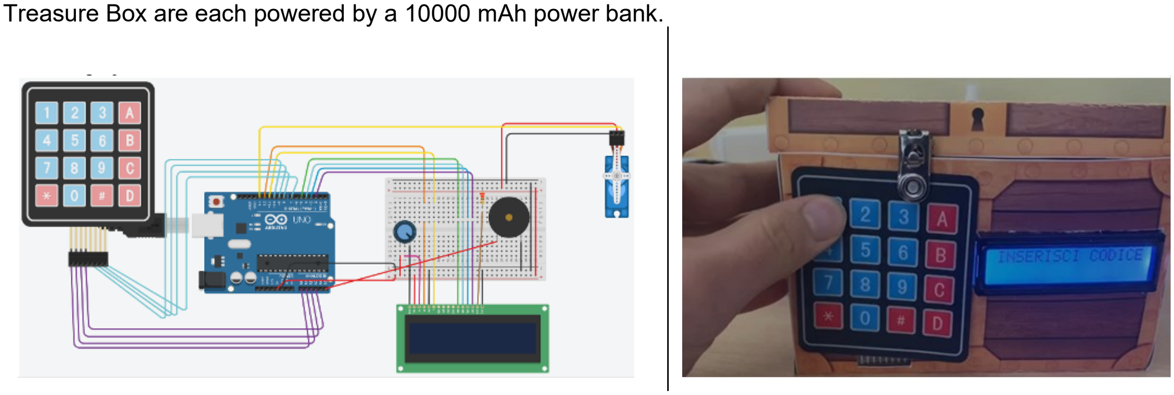
The first smart object of the *Magic Torch* application was the *Smart Torch*; it is composed of an RFID reader capable of detecting data from *tags* such as smart cards, an LCD screen, 3 RGB LEDs, a sound buzzer, and an Arduino microcontroller. The LED and buzzer are used to provide visual and audible feedback, where the green LED indicates a correct response, the red LED indicates an incorrect response, and the blue indicates "waiting" and setup status. Figure 2 shows the circuit diagram of the Smart Torch on the left side and the final smart object. Due to the shell made of cardboard, the player can comfortably carry using the cone handle and can easily bring close to a tag when needed on the right side. To remotely control the behavior of the sensors and actuators embedded in IoT smart objects, RESTful APIs were created in the EUD platform *EFESTO-5 W* to trigger ECA rules or execute actions when a rule is activated. These APIs were registered by the IT experts in EFESTO-5 W (first layer of the meta-design approach). Specifically, for *Magic Torch*, the RFID API generates an event that is triggered when a tag is read and returns the value of the card; the LED API generates an action to activate an LED; the LCD API generates an action that shows a text on the *Magic Torch* screen; and finally, the buzzer API sounds.



a b

Figure 2. The Magic Torch IoT circuit (a) and the final smart object (b).

The second IoT smart object is the *Smart Treasure Box*. This box is equipped with a 4x4 keypad, a sound buzzer, an LCD screen, and a servo motor. The keypad is used to enable input from the players to access the key that opens the box. The screen and the buzzer provide feedback about what is being typed by the visitor. Initially, the display shows only the message "Insert code:"; subsequently, during the symbol input, the characters are shown one after the other. If the final code is correct, the message "Correct!" is displayed, and if the code is not correct, the message "Wrong code!" is displayed. Additionally, in this case, RESTful APIs were created, and for Smart Torch, these functions were registered in *EFESTO-5 W*. Specifically, the keypad API generates an event that is triggered when the key is completely entered; the buzzer API produces an action to play a sound; the LCD API generates an action that shows text on the screen; and finally, the servo motor API produces an action to turn the gears and lifts the lid of the chest. Figure 3 shows the circuit diagram of the Smart Treasure Box on the left side and the final smart object on the right side. The Smart Torches and the Smart Treasure Box are each powered by a 10000 mAh power bank.



a b

Figure 3. The smart Treasure Box IoT circuit (a) and the final smart object (b).

The IoT game also includes smart cards. They have the shape of playing cards and have embedded RFID tags so that they can be recognized by the Magic Torch. Because of the use of the reader in the Smart Torch, we used MIFARE tags. We created two types of cards: riddle cards and answer cards. The riddle cards have the riddle text printed on the card so that players can read the text. The answer cards are positioned close to the artifacts that must be identified during the game; the cards have a target printed on them to indicate to the players that they have to put the Magic Torch on the target to indicate that the artifact is the answer to the riddle (see Figure 4b). In total, we created 7 riddle cards and 49 answer cards, 7 for the correct answers and the remaining 42 for positioning close to the artifacts that were wrong answers.

4. EXPLORATORY STUDY

As stated in the introduction and related work, little research has been conducted on the impact of IoT technology on museum visitors. Specifically, how the IoT influences visitors in terms of emotions, overall experience, and workload has scarcely been investigated in the literature. To investigate the impact of introducing an IoT game during a museum visit, we performed the exploratory study reported in this section.

4.1 Study Design and Participants

The main goal of the performed study is to start exploring the strengths and weaknesses of playing an IoT game during a museum visit and to investigate which factors contribute either positively or negatively to the visitor experience. With this goal in mind, we formulated the following 3 research questions:

- RQ1: Are visitors' emotions affected by playing an IoT game during a museum visit?
- RQ2: How does playing an IoT game during a museum visit impact the overall experience?
- RQ3: How does playing an IoT game during a museum visit impact visitor workload?

For the study, we adopted a repeated measures design, in which a group of participants is assessed both before and after the application of a treatment [55]. Measures were collected based on a pretest-posttest evaluation. First, participants were tested during the guided tour of the Museum of Natural Sciences (pre test). This phase provided baseline measures accounting for personal idiosyncrasies. Participants were then tested during the game (post test), which was considered as the treatment. During the two phases, various data were collected to answer the above research questions (see Section 4.2). Moreover, participants were observed by 5 evaluators (some of the authors of this article); 3 of the evaluators videotaped the two phases of the study.

The study was conducted on June 22nd, 2022, at the Museum of Natural Sciences on the Campus of the University of Bari. The museum has an area of approximately 1000 square meters and consists of two sectors: 1) Geopaleontological and 2) Mineralogical-Petrographic. The exhibition is large and very interesting; it also shows old tools used for the study of Earth Sciences, such as one of the first seismographs in the world. For the study, together with the museum experts, we chose an area of the geopaleontological sector, which has a rich exhibition of prehistorical animals.

A professional museum guide led visitors on the tour. Since most visitors to this museum are younger than 30 years old, we recruited people aged between 18 and 25 years. Recruitment started two weeks before the study through convenience sampling. A total of 30 candidates were contacted, 18 of whom eventually completed the study (6 females; average = 21.83; standard deviation = 1.93). Each participant signed a consent form and was rewarded at the end of the study with a kit containing a bag, a pen, a tourist guidebook of the Apulia region, and a t-shirt.

4.2 Measurements and instruments

Quantitative data were primarily collected to address the research questions. For RQ1, which relates to visitors' emotions, we considered several options for measuring visitors' affective states, specifically facial expression analysis [56], noninvasive low-cost sensors [57], brain-computer interfaces [58], and questionnaires. Given the nature of the game, which requires visitors to move in a large space, we discarded facial expression analysis because it required the installation of dozens of cameras; sensors were avoided because they are too sensitive to body movements; and brain–computer interfaces were considered too invasive. Thus, questionnaires were considered the best option despite some intrinsic limitations, such as self-reports and the requirement of visitors to stop their activities to complete the questionnaire. We adopted the Self-Assessment Manikin (SAM) questionnaire [41], which is a validated and economical self-reporting questionnaire for assessing the emotional states of a person. SAM considers three dimensions: pleasure, arousal, and dominance. Participants rate their emotional states in each dimension using a 9-point pictorial scale. The pleasure dimension measures the level of positive or negative affect perceived by the person, the arousal dimension measures the level of person activation or calmness, and the dominance dimension measures the level of control or lack of control by the person. Given its nonverbal design, the questionnaire is readable by people regardless of age, language skill, or other factors. To avoid disturbing visitors by requiring them to complete several SAMs, the professional guide asked them to complete the questionnaire 5 times during the guided tour, specifically after she explained a group of artifacts (an explanation lasted approximately 3 minutes), and 7 times during the IoT game, specifically at the end of each riddle.

Concerning RQ2, to measure the visitor experience, we adopted the short version of the User Experience Questionnaire (UEQ-S) [59]. In the literature, the UEQ-S is considered a reliable questionnaire for measuring people's subjective impressions of their experience, providing insights into the strengths and weaknesses of their experience. The UEQ-S allows for quick assessment of a person's experience in specific scenarios and is not necessarily tied to technology; filling out the entire UEQ may be impractical because it consists of 8 items that measure the hedonic and pragmatic quality aspects of the experience perceived by the person. Hedonic quality comprises emotional and experiential aspects; it assesses people's perceptions of product/service attractiveness and novelty, as well as enjoyment, through 4 items with a semantic differential scale whose polar adjectives are *unpleasant/pleasant, unattractive/attractive, boring/exciting, and frustrating/satisfying*. Pragmatic quality comprises the functional and utilitarian aspects of the experience; it assesses a person's perceptions of the product/service efficiency, effectiveness and usefulness in achieving their goals through 4 items: obstructive/supportive, complicated/simple, inefficient/efficient, and ineffective/effective. The seven-point scale ranges between -3 (extremely bad) and +3 (extremely good). Resulting values between -0.8 and 0.8 indicate a neutral evaluation, values > 0.8 indicate a positive evaluation, and values < -0.8 indicate a negative evaluation.

For RQ3, which refers to visitor workload, we administered the NASA-TLX questionnaire as "Raw TLX" [60]. It is a widely used tool for assessing the subjective workload and mental demands experienced by individuals performing various tasks. It was originally developed by the National Aeronautics and Space Administration (NASA) to evaluate the workload of pilots and has been applied in various domains, including driving, healthcare, and human-computer interaction. It consists of 6 items that rate the perceived workload along 6 subjective dimensions, i.e., *mental demand*, *physical demand*, *temporal demand*, *performance*, *effort*, and *frustration*. Participants rate each dimension on a scale of 0 to 100, indicating their perceived workload or demand. The ratings are subsequently combined to calculate the overall NASA-TLX workload index, which represents the total subjective workload experienced by the participants [61]. The administered questionnaires, i.e., SAM, UEQ-S and NASA-TLX, are reported in the Appendix.

For a deeper analysis of emotions (i.e., concerning RQ1), we took notes and recorded audio and video of both the guided tour and the game playing. We decided to analyze the collected qualitative data [62] with thematic analysis [63]; this technique also provides valuable information about people's engagement and satisfaction and can help identify patterns and trends in people's behaviors. First, videos and notes taken by the observers during the study were examined, and actions, gestures, facial expressions, and other nonverbal cues were transcribed. According to the thematic analysis protocol, 3 evaluators performed the following 6 steps: *familiarizing with the data, generating codes, mapping together codes that share similar meanings, reviewing potential themes, defining and naming themes, and producing a report.* Familiarizing involves identifying items of interest and preparing a baseline for subsequent steps. Generating codes means defining labels that describe the interesting aspects of the data and highlighting relevant sentences in the transcripts; these short descriptions capture the essence and meaning of the highlighted data. Mapping between codes and themes helps identify the most relevant and recurring codes that better describe the data. Reviewing potential themes helps refine and understand whether the identified themes provide a proper and accurate description of the data. Each theme should be accompanied by a short description that defines its meaning. The report then describes the analytic commentary, extracted data, and defined themes (hereafter referred to as patterns because they reflect the behavioral patterns of visitors).

a b

Figure 4. (a) The professional guide is talking to some participants during the tour; (b) during the game, a player touches a smart card with the Magic Torch to select an artifact.

4.3 Procedure

The procedure adopted in the study was as follows. The participants first took a traditional guided tour, during which the guide showed the museum exhibits; at the end, they played the game (see Figure 4). The 18 participants were divided into 2 groups of 10 and 8 visitors to limit the number of visitors to each guided tour. The two groups underwent the same procedure. The group of 10 participants started first. At the beginning of the guided tour, each participant received a sheet with 5 printouts of the SAM questionnaire, a sheet reporting the UEQ-S and NASA-TLX posttest questionnaires, and a pen. During the tour, the guide stopped the visit five times (at the end of the explanation of a group of artifacts) for approximately 15 seconds, and the participants were asked to complete the SAM questionnaire. The tour lasted approximately 20 minutes. At the end, the visitors were asked to complete the UEQ-S and NASA-TLX questionnaires.

After the guided tour, the participants were divided into teams of 2 (pairs), and each team at the time played the *Magic Torch* game according to the description in Section 3.1. Before starting the game, the two players received a *Magic Torch* and 7 cards with the riddles to identify the correct artifact; each of them also received a sheet with 7 printouts of the SAM questionnaire, a sheet with the UEQ-S and NASA-TLX posttest questionnaires, and a pen. Each player was asked to complete the SAM questionnaire after finding the artifact they believed solved the riddle; even if the artifact was not the correct one, the players completed their SAM questionnaires and, afterward, kept looking for the correct artifact. All the correct artifacts had to be found since their codes were required to complete the keyword that opened the treasure box. At the end of the game, the players completed the posttest questionnaires.

The entire procedure was preliminarily assessed through a pilot study with 3 pairs of people. The pilot test was instrumental in improving the clarity of the riddles written on the cards.

4.4 Quantitative Data Analysis and Results

The quantitative data collected during the guided tour and during the game were analyzed via statistical tests. Specifically, Welch's t test (also called the unequal variances t test) was used to analyze visitors' emotions resulting from the SAM questionnaires completed by the 18 participants (variance violation assessed with the Shapiro–Wilk test). A paired sample t test was computed to analyze the NASA-TLX and UEQ-S results since they did not violate a normal distribution (assessed with the Shapiro–Wilk test). An alpha level of .05 was used for all the statistical tests.

For RQ1, we measured the visitors' emotions in two parts of the study: during the traditional guided tour and during the IoT game. The three emotional states of the SAM questionnaire, i.e., pleasure, arousal, and dominance, were compared (see Figure 5), and for all of them, a significant difference emerged ($\chi_{(127,465)\ pleasure} = 41.461$, $p = .000$; $\chi_{(146.094)\ arousal} = 67.852$, $p = .000$; $\chi_{(123.240)\ dominance} = 47.041$, $p = .000$) in favor of the IoT game.

To analyze RQ2, we computed and compared the overall UEQ-S score and the scores of its subdimensions, i.e., hedonic and pragmatic qualities (see Figure 6). According to the interpretation guidelines of the UEQ-S, the overall UEQ-S obtained a good score ($\bar{x} = 1.51$, $SD = 0.99$), the pragmatic quality obtained a particularly excellent score ($\bar{x} = 1.83$, $SD = 0.86$), and the hedonic quality obtained a lower score ($\bar{x} = 1.20$, $SD = 1.22$). In contrast, the IoT game resulted in an excellent overall score ($\bar{x} = 2.44$, $SD = 0.39$), with excellent scores for both the hedonic ($\bar{x} = 2.68$, $SD = 0.35$) and pragmatic ($\bar{x} = 2.21$, $SD = 0.53$) qualities. A statistically significant difference emerged in favor of the use of IoT technology for the overall score ($t_{(17)} = 4.302$, $p < 0.000$), hedonic quality ($t_{(17)} = 5.491$, $p < 0.000$), and pragmatic quality ($t_{(17)} = 2.085$, $p = 0.050$).

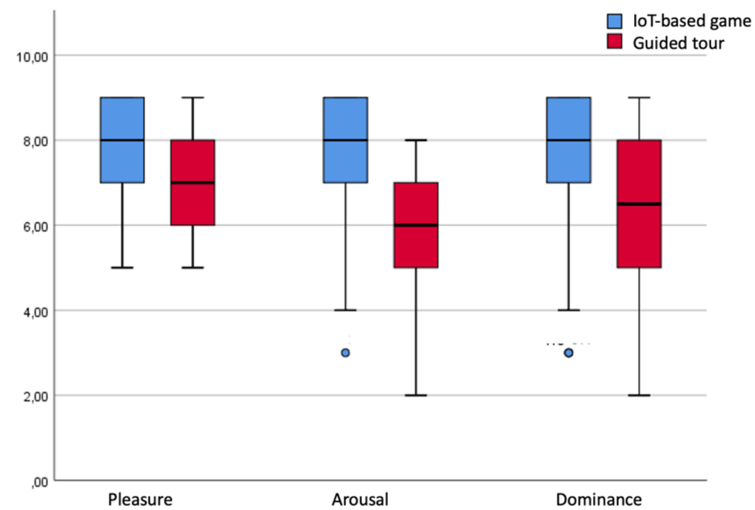


Figure 5. Box plots of the emotions felt by visitors during the guided tour (red) and the IoT-based game (blue).

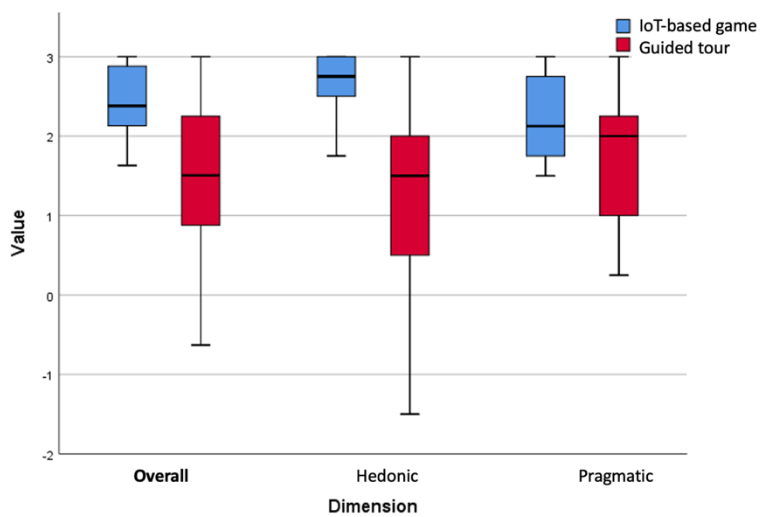


Figure 6. Box plots of the UEQ-S results and subdimensions during the guided tour (red) and the IoT-based game (blue).

For RQ3, we compared the visitors' workloads in the two parts of the study. A significant difference emerged ($t_{(17)} = 2.852$, $p < 0.012$). A more detailed analysis of workload was carried out by comparing the values along the six dimensions of the NASA-TLX (see Figure 7). Significant differences existed for *mental demand* ($t_{(17)} = 2.668$, $p < 0.016$), *physical demand* ($t_{(17)} = 2.778$, $p < 0.013$), *temporal demand* ($t_{(17)} = 3.145$, $p < 0.006$), and *performance* ($t_{(17)} = -2.251$, $p < 0.022$); however, no differences emerged for *effort* ($t_{(17)} = 1.170$, $p < 0.258$) or *frustration* ($t_{(17)} = 1.011$, $p < 0.326$).

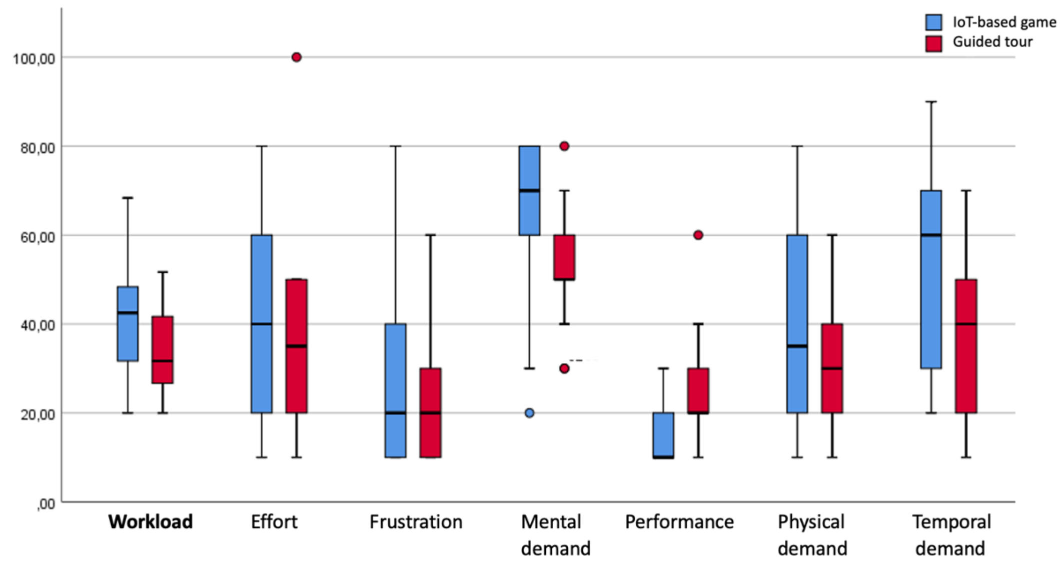


Figure 7. Box plots of the workload and its subdimensions during the guided tour (red) and the IoT-based game (blue).

4.5 Qualitative Data Analysis and Results

As we said in Section 4.2, we took notes and recorded the audio and video of both the guided tour and the game playing. However, we decided to analyze only the recordings of the game because there is nothing special to highlight during the guided tour: the visitors did not show any unusual behavior, they followed the guide through the various planned stages, and in a few sporadic cases asked questions. In the case of the Magic Torch game, on the other hand, its active role allowed dynamics and behavior worthy of attention to emerge.

Several useful insights came from the analysis of notes and videos of the participants during the *Magic Torch* game. To solve these riddles, some players preferred to use a thorough approach, meticulously examining each clue and item; others relied on intuition to quickly establish connections between the clues and artifacts. By examining the players' interactions within each pair and with smart objects (torch, cards and treasure box), we discovered interesting patterns of how players approach and resolve riddles, as well as their behaviors. The patterns that emerged are primarily related to two dimensions, which we call the *individual dimension* and *collaboration dimension.* The three patterns related to the *individual dimensions* are illustrated in the following.

- *Creative thinking*. In solving riddles, players sometimes use their own creativity to explore alternative perspectives and to draw unexpected connections between clues and artifacts instead of trying to remember what the guide says and relying on their expertise or other factors unrelated to the guided tour [64]. For example, player 1 of team 1 said "Maybe the riddle description on this card matches the description on the card close to the artifact", thus suggesting a possible clue to identifying the artifact.
- *Cultural Knowledge and Context*. The way the players solved the riddles was impacted by their knowledge of the museum's artifacts and their cultural backgrounds. Interpreting clues and solving riddles appeared easier for those who had a better understanding of the cultural context and historical value of the artifacts,

as shown by certain pairs who were able to use their prior knowledge to do so [65]. For example, player 2 of team 5 said, “Based on my knowledge of the Jurassic, I think the clue refers to the rhinoceros”.

- *Adaptability and Flexibility*. Players also appeared to be open to their teammate's ideas and willing to adjust their individual strategies to address their riddles. For instance, player 1 of team 4 said, “Initially, I had another idea to solve the riddle, but now I think your idea of connecting the clue to your proposal is worth exploring. Let us delve deeper into that and see if we can find any connections to an artifact”.

Four patterns related to the *collaboration* dimension emerged, as reported below.

- *Knowledge sharing*: Players shared relevant information acquired during the tour, as well as insights and observations, with their teammates. Most teams engaged in active discussions and shared ideas and built upon each other's thoughts to arrive at the correct solutions. For example, player 1 of team 3 said, "I remember that herbivorous mammals are in that area of the museum", and player 2, when they reached that area, replied, "OK! Having big teeth, it should be the rhinoceros". By pooling their knowledge and combining their perspectives, they enhanced their problem-solving abilities and increased their chances of solving riddles.
- *Support and Encouragement*: In several cases, players encouraged, motivated, and positively reinforced their teammates. For example, player 2 of team 7 said, “I love how we are working together as a team. Your contributions are valuable, and I'm confident we will solve this riddle”.
- *Conflict Resolution*: Players showed the ability to effectively manage conflicts and find constructive solutions. They often engaged in respectful discussions, considered different viewpoints, and worked toward consensus. For example, player 1 of team 3 said, “It appears to be we have different interpretations of this clue. Let us take a moment to listen to each other's reasoning and find common ground that combines our insights”.
- *Communication*. In general, the two players on a team communicated with each other very actively, even if they were not familiar with each other. Only a couple of teams struggled with communication at the beginning of the game, perhaps because the two players were both too shy and because some awkwardness between them led to misunderstandings or difficulties in coordinating their efforts. Notably, team 9 decided to solve the riddles by adopting a very interesting communication strategy: at the beginning of each riddle, each player communicated his or her idea of a solution, and then, in turn, they criticized or accepted their teammate's idea, discussing it until they converged on a solution.

To assess **players’ engagement**, we observed their facial expressions, body language, and overall behaviors. We observed that, for all pairs, *engagement was high throughout the game,* remaining high for all seven riddles regardless of the order considered by each pair. This is confirmed by the quantitative data that resulted from the SAM questionnaires completed by players after solving each riddle; as reported in Section 4.4, the values of pleasure, arousal, and dominance were significantly greater than the values collected during the guided tour. The general dynamics of the game were very similar for all pairs: the players chose a card after picking up the torch and reading it aloud; in most cases, the players actively discussed and tried to remember what the guide said to identify the correct answer, walking through the corridors of the museum looking carefully for the correct artifact. We observed that they wanted to be *very fast*; although there were no time constraints, one-third of the pairs walked fast or even ran and read the questions very frantically. We also observed that *many pairs cheered loudly* when they found an artifact that solved the riddle or regretted with loud exclamations when they reached the wrong artifact. For example, player 1 of team 1 said, “Yay! This riddle is also done! We are awesome!” or player 2 of team 4 said "Come on, come on, just one more riddle and then we are done". We can conclude that the players had fun with *Magic Torch*, as each of them wanted to hold it and they exchanged it often, and they greatly enjoyed when the torch emitted the sound for a correct answer.

5. DISCUSSION AND LESSONS LEARNED

The overall goal of this exploratory study was to begin to elucidate whether and how playing IoT-based games impacts visitor experience. In the following section, the main findings of the study are discussed, and implications and contributions are distilled in the form of lessons learned, which shows the great potential of IoT solutions at CH sites.

Playing an IoT-based game during a museum visit increases visitors’ engagement and positive emotions (RQ1). The study results, in particular those related to RQ1, suggest that the use of IoT devices in a museum context positively influences visitors' engagement and emotional experiences. In terms of engagement, the video analysis revealed that the players were actively involved throughout the IoT game, from the beginning to the end, and in several cases, they had very enthusiastic attitudes and behaviors. In this context, positive engagement is often considered a trigger for consolidating the knowledge acquired during museum visits, which is a fundamental aspect of such visits [66-68]. The quantitative data collected to evaluate emotional experience indicated that pleasure, arousal, and dominance had significantly greater values than did traditional guided tours. In fact, higher pleasure scores suggest that the IoT game had a positive impact on visitors’ experience, indicating that most visitors enjoyed playing the game. Instead, arousal indicates a high level of physiological and psychological activation experienced by museum visitors while using IoT devices. This finding suggested that the visitors were engaged and interested in the museum visit, while lower levels of arousal during the guided tour sometimes indicated that they might have been bored or disinterested. Finally, the dominance dimension of the SAM questionnaire indicates that the visitors using the IoT devices felt more in control and empowered during the game. This could be because the visitors were able to navigate the museum and interact with the exhibits at their own pace and discretion rather than being guided by someone else. This may also indicate that the use of technology in the museum context can enhance visitors' sense of control and autonomy, both of which contribute to a more positive experience. However, these results are based on self-reported data from a single questionnaire, and further studies may be needed to confirm these findings and explore other factors that may influence visitors' experiences.

IoT-based games for museum visits may improve the hedonic quality aspect of visitor experience (RQ2). From the study results, both quantitatively (see Figure 6 in Section 4.4) and qualitatively (see Section 4.5), the hedonic quality aspect of visitor experience was significantly enhanced when playing the IoT game. The hedonic aspect is important when visiting CH sites because it refers to the emotional and affective experience that visitors have while exploring the site. Visitors may have different levels of interest and engagement with a site, and their enjoyment can be influenced by factors such as the attractive layout of exhibits, the presentation of information, and the excitement generated by the activities they perform during the visit. The study revealed that playing the IoT game aroused more positive emotional responses from visitors and created more engaging experiences. As suggested by the *creative thinking* pattern, the IoT game was able to increase the players’ creativity by allowing them to explore alternative perspectives and establish surprising connections between the clues on the smart cards and the artifacts available in the museum. Three of the identified patterns, namely, *Support and Encouragement*, *Adaptability and Flexibility*, and *Knowledge sharing*, indicate that the game enabled the players to encourage, motivate, and reinforce their teammates when the wrong action was performed and to share relevant information acquired during the tour, as well as insights and observations with them; thus, the IoT game strongly impacted the emotional experiences of the players. Moreover, in case of conflicts, the players were able to effectively solve them, as suggested by the *conflict resolution* pattern. Overall, by paying attention to the hedonic aspects of the visitor experience, it is possible to create more satisfying and memorable experiences, leading to increased visitor engagement, positive word-of-mouth, and greater support for appreciating and promoting CH.

IoT-based games may improve the pragmatic quality aspect of visitor experience (RQ2). In the short form of the User Experience Questionnaire (UEQ-S), the pragmatic quality aspect of visitors' experience indicates the perceived efficiency and effectiveness of a product, i.e., it refers to the more pragmatic concept of usability; it directly affects users' ability to accomplish their tasks with the product, which ultimately impacts their overall satisfaction. The results of the UEQ-S indicated that the visitors found the IoT-based game supportive, efficient, and effective at helping them achieve their goals more than the guided tour. This indicates that the game provided a good level of support for practical aspects of museum visits, such as navigation, information seeking, and artifact exploration. As suggested by the *Cultural Knowledge and Context* patterns, the IoT game led players to define relations between their cultural backgrounds and the museum's artifacts to solve the riddles. High scores for the pragmatic quality aspect are generally a positive outcome, as they indicate that users were satisfied with the usability and functionality of the game and that it was successful in enhancing the museum visit. Thus, designers must devote special attention to creating games that are able to provide a valuable pragmatic experience. The meta-design adopted for *Magic Torch* involved many users and domain experts; the latter knew what had a positive impact on visitors and how to valorize the most interesting artifacts available in the museum.

The trade-off between emotions/experience and workload deserves attention (RQ3). In the present study, a greater workload while playing the game resulted in higher scores (and therefore a greater workload) for mental, physical, and temporal demands but also higher scores (and therefore a lower workload) for performance. Indeed, these results indicate that the use of IoT devices requires more cognitive and physical effort from participants and places greater demands on their time. This could be due to the need to interact with technology while visiting the museum. Higher performance scores suggest that the visitors felt more efficient and successful in playing the game with the help of technology. However, higher scores on other subscales, such as mental and physical demand, indicate that the increase in performance came at the cost of increased cognitive and physical effort. Higher temporal demand scores indicate that the participants felt they had to act quickly and complete the task within a limited time frame. It is worth remarking that the higher workload score is due not only to using IoT devices but also to game mechanisms. In fact, the players are required to participate more proactively in the visit because they must solve the riddles of the game. This requires more cognitive effort than a guided tour, during which visitors are more passive, primarily listening to what the guide tells them. At first glance, a greater workload may appear to be a negative result; however, when comparing these results with those obtained by the UEQ-S and SAM questionnaires, this is actually a positive finding of our study since we can safely say that even if the workload was higher during the game, this was well accepted by the players and did not affect their positive emotions or experience. However, the trade-off between emotions/experience and workload requires additional investigation.

6. STUDY LIMITATIONS

We are aware that some issues might have limited the internal and external validity of the study [62]. We briefly discuss them to highlight the conditions under which the study design offers indications that can be exploited in other contexts and the conditions under which it might fail.

Internal validity is the degree of confidence that the causal relationship tested in this study is not influenced by other factors or variables. We report two possible threats, explaining how we have mitigated them.

- *Understandability of the material*. A pilot study with 3 teams was carried out before the experiment to assess the entire procedure and to ensure the understandability of the material (e.g., clarity of the questions reported on the card, use of the IoT devices).
- *Design of the gaming experience*. After the guided tour, the pairs of participants played the *Magic Torch* game sequentially, each pair at a time. This might have negatively affected the performance of the last pairs, who, due to the waiting time, might have had more difficulty remembering the guide's explanations, impacting the experience of the game. However, in our study, this was mitigated by the fact that the time between the guided tour and the last team's game was not too long.

External validity relates to the possibility of generalizing the study's findings to other contexts. In this respect, the main threats to our study are as follows:

- *Participants' age*. The participants recruited in our study were aged between 18 and 25 years. Many museum visitors are aged between 9 and 30 years. Further studies that include younger pupils must be carried out to further generalize the results.
- *Evaluated IoT Application*. The study focuses on a specific IoT-based game called *Magic Torch*, which was designed for soliciting visitors to better reflect on artifacts in museums. Not all the findings may be generalizable to other types of IoT-based games at CH sites.
- *Selection Bias*: As an exploratory study, we considered a relatively small sample (18 visitors); this might limit the generalizability of the findings.

7. CONCLUSION AND FUTURE WORK

The research reported in this article was conducted with the aim of shedding some light on whether and how the use of IoT technology in a museum affects the visitor experience, an aspect that has been marginally addressed in the literature. We performed an exploratory study to evaluate whether and how playing an IoT-based game affects the experience of museum visitors. This first study showed the great potential of IoT technology for improving the visitor experience, especially from an emotional point of view, which is a key aspect in attracting people to visit CH sites and appreciate artifacts on display. The positive emotions and values of the UEQ-S questionnaire, which measures the experience felt by a visitor, were greater during the game than during a traditional guided tour. It was also found that the visitor workload was greater than that of a traditional guided tour because visitors were required to actively participate in solving game riddles; however, their experiences and emotions were not negatively affected.

Of course, this is only one step toward a broader analysis of the use of the IoT in CH, and studies should be conducted with other formats of IoT applications, e.g., replacing guided tours with only IoT solutions and observing the behavior of users of different ages with different interests, skills and cultures. Furthermore, it could be interesting to study the impact of IoT games during museum visits from an educational point of view. Investigating how the introduction of the IoT during a visit, which we have seen in this study as positively impacting visitor experience, can also improve the learning of the content shown by the guide and/or displayed in the museum.

The introduction of mobile devices and advanced sensors such as AR helmets, combined with tangible IoT objects customized by CH experts, can contribute to expanding the modes of interaction with cultural objects and sites; of course, whether this increase in potential for higher involvement of visitors who, depending on their preferences, can configure their experiences by selecting the degree of technology and sensors available at CH sites should be investigated.

ACKNOWLEDGMENTS

This work is partially supported by the Italian Ministry of University and Research (MIUR) under grant PRIN 2017 "EMPATHY: Empowering People in dealing with internet of Things ecosYstems". F. Balducci acknowledges the support of the REsearch For INnovation (REFIN) grant, CUP:H94I20000410008 cod. F517D521 POR Puglia FESR FSE 2014-2020 "Gestione di oggetti intelligenti per migliorare le esperienze di visita di siti di interesse culturale". The authors are very grateful to the Museum of Natural Sciences of the University of Bari Aldo Moro, in particular to Vincenza Montenegro, Director of the Museum System of the University of Bari, and to Nicola Venisti, Director of the Museum of Natural Sciences, for their support in the creation of the Magic Torch game and in the design and execution of the exploratory study. The authors also thank Nicole Novielli, Associate Professor at the Computer Science Department of the University of Bari, for valuable discussions on some options to measure users' affective states, specifically noninvasive low-cost sensors.

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