Introduction

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This work summarizes the outcome of the project “CultureID”, co-funded by the European Union and Greek national funds. The project aims to implement technologies like the Internet of Things, Robotics, Big Data analysis, and Artificial Intelligence in the field of cultural heritage. In this context, the group exploits RFID technology to: *i*) develop a complete solution for the collection management of the Archaeological Museum of Thessaloniki, *ii*) provide location-based guided tours to the visitors, *iii*) track the visitors’ interests with respect to the museum’s artifacts, and *iv*) present new forms of interactions by introducing a prototype RFID-enabled social robot. Partners in the project are the “Archaeological Museum of Thessaloniki”, the “School of Electrical and Computer Engineering” of the “Aristotle University of Thessaloniki”, the “Department of Educational & Social Policy” from the “University of Macedonia”, and two companies, “Trinity Systems” and “Kenotom”. The interdisciplinarity of the project demands expertise in Archaeology, Restoration, Electrical Engineering, Robotics in Education etc.

RFID technology has been embraced in several museums. In the Metropolitan Museum of Art, New York, battery powered RFID sensor cards are employed to gather and analyze data regarding the physical environment in which its artwork is displayed. The National Taiwan Museum of Fine Art and the National Gallery of Singapore has adopted RFID technology to manage the movements of its artwork and visitors into and out of its warehouse, and to identify the locations of works of art. In the Exploratorium at San Francisco, the Museum of Science and Industry in Chicago, the Vienna Museum of Technology, the Tech Museum at San Jose, the Horsens Prison Museum in Denmark, the International Spy Museum in Washington DC, the Museum of Natural History in Aarhus Denmark, the visitors interact with the exhibits through RFID technology, gamifying their educational experience (Karimi, Nanopoulos and Schmidt-Thieme 2012).

Similarly to Taiwan and Singapore, we also exploit RFID technology to track and automatically update the movements of artifacts inside the museum, extending the coverage not only in the warehouse, but also in the exhibition area. As in the aforementioned museums, we also deploy RFID technology to gamify the experience but in a different manner. In our case, within the games, a portable RFID reader, aids the “players” to discover hints, in order to solve a riddle game presented by the robot, as will be explained in the manuscript. Furthermore, RFID technology is exploited to provide location-dependent guided tours in the smartphones of the visitors, while it quantifies the interests of the visitors, with respect to the exhibits.

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Furthermore, social-robots are increasingly adopted in museums around the world. An overview of social robotics and its potential use in museums is given in (Hellou et al. 2022). Typically, museums use social robots for short interactions with visitors, e.g. the use of robot “Pepper” in the Smithsonian's Hirshhorn Museum or as a tour guide.

Compared to the aforementioned deployment of social robots, we propose engagement of our robot in games with younger visitors. The robot is the presenter and host of a “game” posing riddles to the players and rewarding them for correct answers. Interestingly, the structure of the game ultimately leads the players to focus on the actual information related with the exhibits, thus encouraging interaction with the physical world and avoiding interactions through a screen. In addition, through a different action, as already done in other museums, the robot is able to engage in discussions around the most popular exhibits of the museum.

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Wrapping up, ~~In~~ in the context of our project, we have adopted well established practices for exploiting RFID technology, Robotics and Artificial Intelligence to enhance the visitors’ experience and support the museum’s personnel with valuable information. From the perspective of the Museum’s personnel, RFID technology is used to track visitors and artwork inside the Museum. As a result, restoration processes as well as transfer of ancient artifacts for various purposes (e.g. analyses, study, temporal exhibitions etc.) are automatically triggered and stored in the Museum’s database, while statistics with respect to the visitors’ interests are generated. As for the visitors, they can enjoy guided-tours in their smartphone, in the vicinity of their location, identified by RFID technology. They can join discussion with the robot around major exhibits of the museum. Younger visitors play games with the robot, while a portable RFID reader is used as an assistant that guides them towards the solution of a riddle. The basics of RFID technology is presented in Section I, replacing traditional tracking processes that were typically carried out by pen and spreadsheets. In principle, the technology involves an RFID-reader that identifies an RFID-tag; this event triggers a query to an asset-management software and depending on the application, action of reading or writing information in a database.

Section I. ~~RFID technology~~Exploitation of RFID technology

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The basic units of an RFID system are the RFID-reader and the RFID-tag. An RFID-tag is typically passive (battery-less), low cost (~0.01€) and comprises a chip and an antenna. The tag gets powered-up by the reader and back-scatters its unique id, stored in its internal memory. The group has attached at least one tag to each artifact of the museum. As soon as the reader “reads” a tag, a computer, connected to the reader ~~it~~ queries the database to retrieve the association with the specific artifact and then access all stored information related to the artifact. This information includes more than 120 fields and lists everything related to the artifact. The reader may scan up to 900 RFID tags per second from a distance as far-away as 14m. Each RFID tag is locked and cannot be reprogrammed by an external RFID reader. Even if a tag is interrogated by another reader, the related information in the database will not be accessed. The tags represent the keys to information, provided that the computer (that uses those keys) has access to the database.

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~~Section II. Exploitation of RFID technology~~

We have developed a web-based application for the entire management of the Museum. The app gives access to different content, depending on authentication-level of the museum’s personnel. The app collects (and stores) information from the database. The database includes all information related to the following applications.

A. **Continuous tracing of the artifacts**

Our first aim was continuous monitoring and automated registration (tracing) of the artifacts’ relocation within the museum as well as their participation in temporary exhibitions. The museum hosts more than 40000 artifacts. Restoration and conservation activities, chemical-physical analyses, scientific documentation/study, participation in national and/or international exhibitions require daily relocation of artifacts between discrete areas, including “restoration and archaeometry-facilities”, “storage-areas” and the exhibition itself.

To address that, initially, we had to develop methods to attach RFID tags to each artifact, depending on its material, size and position (in the exhibition or in storage), as shown in Figure 1 [10]. Placement of RFID tags is constrained by the following factors:

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- Requirement for non-visibility of the tags, as it would affect the visual experience in the Museum
- Differences in shapes and materials between the artifacts
- Constraints of the RFID technology, e.g. poor operation in the vicinity of metals.

Figure 1 - Attaching RFID tags to artifacts of the Museum's collection.

Figure 2 - A trolley is used to move RFID-tagged artifacts inside the museum.

The proposed solution is summarized in (Dermenoudi et al. 2021). The entire collection in the exhibition area has been tagged.

Furthermore, personnel are also associated with unique UHF RFID-cards, suitable for placement in badges, hung from the neck. RFID readers have been installed in several locations inside the museum to control the flow of tags, typically moved with a trolley (Figure 2) and personnel. Four antennas are connected to each reader, as shown in Figure 3a, to increase the probability of successful tag-reading and allow for tracking of the visitors as explained next. The readers are hidden inside plastic bases to ensure proper integration in the exhibition area, as shown in Figure 43b.

When a moving tag is identified along with the associated personnel, a "flag" is initialized in the app, forcing the identified employee to store in the database the reason for the relocation of the artifact. This information is linked to the artifact and is added to its "history". This method ensures the digital preservation of each artifact's history.

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~~**Figure 3** - RFID equipment is hidden inside plastic enclosures.~~

~~**Figure 4** - RFID equipment, controlling the flow of visitors, personnel and artifacts, is distributed around the exhibitions areas, storage and restoration facilities of the museum.~~

Figure 3 - RFID equipment, hidden inside plastic enclosures, controlling the flow of visitors, personnel and artifacts, is distributed around the exhibitions areas, storage and restoration facilities of the museum.

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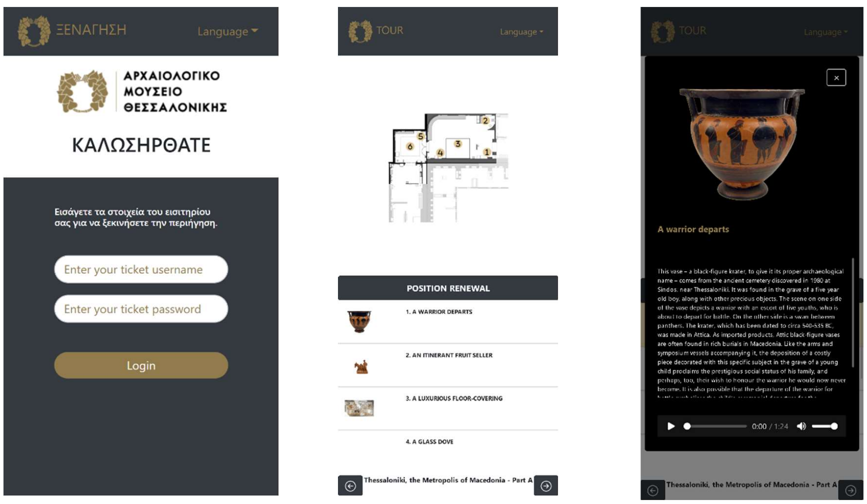
B. Location dependent guided-tours

Secondly, RFID tags were attached to each visitor's ticket. As a result, it has become possible to identify the position of each visitor. We have developed a web-based guide. The visitor may use his/her own smartphones to enjoy the content of the guide, which is automatically updated based on their identified position inside the museum. The corresponding screenshots are shown in Figures ~~5~~4a-—~~7~~4c.



~~**Figure 5** - Guided tour. Login Screen~~a

~~**Figure 6** - Guided tour. The visitor is tracked. Location-dependent content is shown.~~b

~~**Figure 7** - The web-based app runs in the visitor's smartphone. No installation required.~~c

Figure 4 – Screenshots from the location-depndent guided tour running in the visitor's smartphone.

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C. Statistics of Interest

We have developed prototype methods to accurately trace the movement of people inside the museum (Tzitzis et al. 2022), (Megalou et al. 2022), (Tzitzis et al. 2022), (Megalou et al. 2022). By using RFID technology, instead of cameras, we avoid any possibility of identification of a living individual, which would violate GDPR laws. More specifically, each visitor is and remains an unidentified (with respect to one's actual ID) RFID-tag. Hence, monitoring is not mapped to a specific individual, but is only used for statistics; i.e. total-time spent at each artifact, heat maps inside the museum, etc. The museum's management may select different statistics, filtered by the desired date. Such examples are shown in Figures ~~8~~5-~~9~~6.

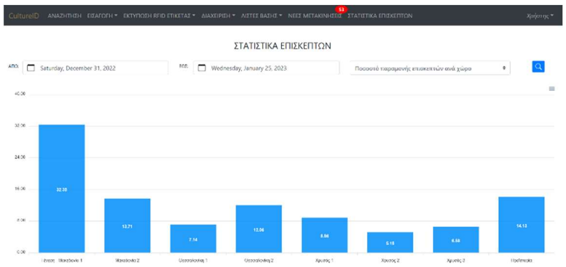

Figure ~~8~~ 5 - Example of statistics of visitors' interest per exhibition area.

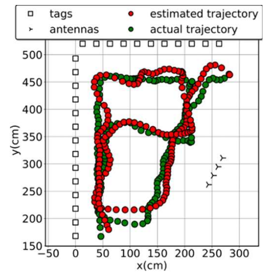

Figure ~~9~~ 6 - Comparative result of the accomplished accuracy in tracking a visitor's trace by RFID technology inside the museum vs. one's actual trace [3].

Section I~~I~~I. Development of a Prototype Social Robot and a Portable RFID reader

We have designed and constructed a prototype Social robot and a portable RFID reader. The robot is equipped with several sensors, actuators and algorithms, in order to support:

- Motion. The robot is able to move safely in the premises of the museum. It avoids obstacles, e.g. visitors, and updates its route dynamically to reach its target.
- Map creation. Suitable sensors allow the robot to create a map of the environment. The map of the museum, created by the robot, is shown in Figure ~~10~~7a. The corresponding actual map is shown in Figure ~~12~~ 7c for comparison.
- Localization of its own pose (position and direction) in the (museum's) map (Filotheou et al. 2022), (Filotheou, Sergiadis and Dimitriou 2022). The robot updates its pose continuously. This allows it to safely navigate in the premises of the museum. For the above three tasks, our strategy was to deploy robust solutions already available in "Robotic Operating System", a collection of open source libraries for applications in robotics and fine-tune or create new codes, whenever the algorithm was inadequate for the museum's environment.
- Real-time 3D localization of all RFID tagged artifacts (Tzitzis et al. 2022). The corresponding result for all museum's exhibits is demonstrated in Figure ~~11~~ 7b and ~~Figure 12~~7c. The entire process lasted a few minutes; the time it took the robot to navigate in the entire exhibition. Localization is accomplished at cm accuracy. Localization of the tags is an expertise developed by researchers of the group and is not widely available in robotics.
- Automatic Speech Recognition. The robot is equipped with directional microphones, which allow it to collect sound, identify the direction of sound and transform speech to text.
- Artificial Intelligence. The text is processed by machine learning algorithms. Then, the robot understands the "meaning" of text, according to the "current" application (e.g. giving information for an exhibit) and responds orally. We have used the RASA open source conversational AI platform. We have designed our conversational model, including "intents" and "entities" and then trained the model to accept possible questions and be able to engage in a discussion related to the trained information. We have also designed another solution, not yet demonstrated to the public, capable to deliver information, related to all exhibits of the museum, allowing the conversational agent running on the robot to have access on the information, already stored in the database.
- Text-to-Speech. The robot is equipped with speakers and appropriate technology to transform the desired "output" text to speech.
- Verbal, Visual, Touch and RFID Interaction with visitors and/or artifacts. It includes a touch screen for haptic interaction, used during the games and the discussions with visitors a

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projector for output~~~~ing visual information on a larger area in the floor, right in front of the robot, microphones and speakers for audio interaction and an RFID reader that allows it to interact with RFID-tagged exhibits and visitors.

The robot has been designed to interact with younger and adult visitors. All parts have been designed in 3D-cad software, as shown in Figures ~~13-14~~8a-8b. The constructed robot is shown in Figure ~~15~~8c.

Younger visitors learn by playing games with the robot, during their visit (Pliasa et al. 2021). In this context, the robot presents stories, related to the exhibits, while showing videos on its screen as well as on the ground through a projector, as shown in Figures. ~~16~~9a-~~18~~c. Then, it poses questions. The answer for each question is related to the museum's artifacts in the surrounding area.

Visitors are encouraged to use a portable RFID reader, which is able to "guide" them to the appropriate location, where the answer is "hidden", again exploiting the RFID tags attached to the artifacts, as shown in Figures ~~19~~10a-c~~-21~~, (Chatzistefanou et al. 2022), (Chatzistefanou et al. 2022), (Chatzistefanou and Dimitriou 2022), (Chatzistefanou, Sergiadis and Dimitriou 2023), (Mylonopoulos et al. 2021). Once they retrieve the answer, they return to the robot to continue with the next "riddle" in this "hidden-treasure-game". Reception of the games by visitors is presented in the next section.

~~**Figure 10** - Museum's map, created by the robot's sensors.~~**a**

~~**Figure 11** - The robot has identified and 3D-localized all RFID-tagged items inside the exhibition, thanks to prototype methods developed by the team.~~**b**

~~**Figure 12** - The positions of the RFID-tagged exhibits have been updated in the museum's map.~~**c**

Figure 7 – (a) Museum's map, created by the robot's sensors. (b) The robot has identified and 3D-localized all RFID-tagged items inside the exhibition, thanks to prototype methods developed by the team. (c) The positions of the RFID-tagged exhibits have been updated in the museum's map.

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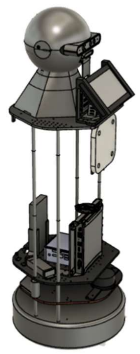

~~Figure 13 – All parts of the robot have been designed in 3D Cad software.~~a

~~Figure 14 - The robot, during the design process.~~b

~~Figure 15 - The constructed robot, outside the museum.~~c

Figure 8 - All parts of the robot have been designed in 3D Cad software, before final construction and assembly.

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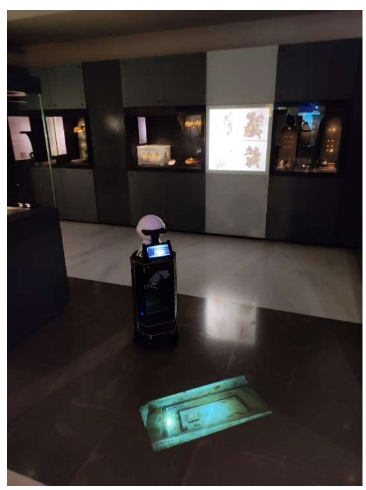
~~Figure 16 - The robot presents a story related to the artifacts~~a

~~Figure 17 - The robots sets questions, related to the artifacts in the surrounding area~~b~~.~~



~~Figure 18 - The screen is also projected on the floor for better visualization of the information.~~c

Figure 9 – (a) The robot presents a story related to the artifacts. (b) The robots sets questions, related to the artifacts in the surrounding area (c) The screen is also projected on the floor for better visualization of the information.

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~~Figure 19 - The "player" selects the exhibit on the portable reader.~~a

~~Figure 20 - The portable reader "guides" the "player" to the correct area, through RFID technology.~~b

~~Figure 21 - The "player" has reached the destination. One should now "find" the answer in this area.~~c

Figure 10. A portable RFID reader "helps" the player in guiding them towards the correct RFID-tagged exhibit, related to the solution of the riddle. (a). The "player" selects the exhibit on the portable reader. (b) The portable reader "guides" the "player" to the correct area, through RFID technology. (c) The "player" has reached the destination. One should now "find" the answer in this area.

Interaction with adult visitors also includes guided-tours and "discussions" with respect to specific exhibits. The robot attracts visitors and shares its knowledge. We have trained the robot by embedding machine learning algorithms, related to the most significant artifacts of the museum. Such a photo is shown in Figure ~~22~~11, while a related video can be seen in "Robot – Conversation demo".

Figure ~~22~~ 11 - The robot gives information by means of discussion with the visitors, thanks to embedded machine learning algorithms.

Section ~~IV~~III. ~~Conclusion~~Discussion

A. Reception from the public

Since March 2023, many schools have visited the museum to play games with the robot. The game is designed for approximately 16 to 20 players, divided in four teams. Each team tries to find the answers to questions set by the robot. A set of questions is grouped around a given thematic area, e.g. "War in Ancient Macedonia", "Everyday Activities in Ancient Greece", "Clothing", etc. Most students that participated were between 9 and 13 years old; though even older and younger students played with the robot. At the end, the students were able to answer all questions set by the robot; they had conquered knowledge, through playing. They were requested to fill an online questionnaire. Figure 12 summarizes some of the results, resulting from the response of 162 students from different schoold and ages.

As shown in Figure 12a, almost 95% of the students rate the robot with 8, 9 or 10, a remarkably big grade for a generation that feels used to technology. Surprisingly, they rate highly the "assistant", i.e. the RFID reader that aided them in the solution of the riddles, as shown in Figure 12b. When asked what they liked most, the prefer the robot, but half students state that they like both the reader and the robot or the reader alone (Figure 12c). The difficulty of the questions appears proper (Figure 12d), while they agree that they have learned new things in an enjoyable way (Figures 12e and f).

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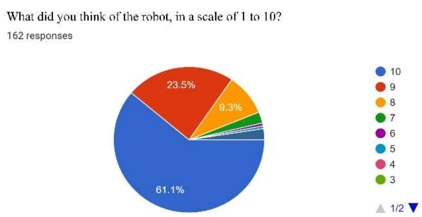

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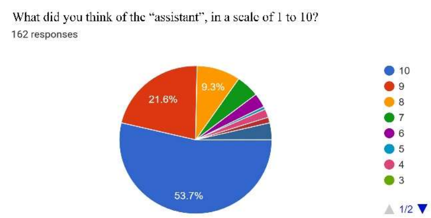

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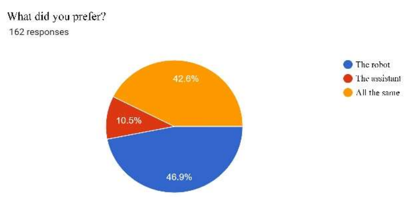

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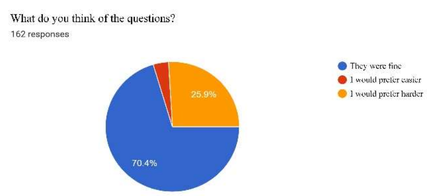

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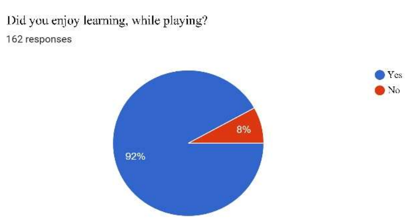

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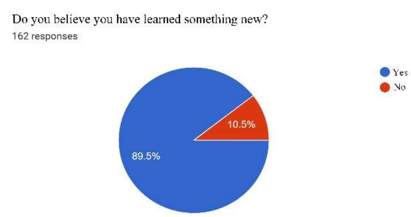
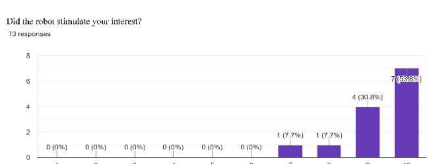


f

Figure 12. Evaluation of the robot by young visitors.

We have also asked adults to rate the conversation with the robot. Unfortunately, they were less willing to spend extra time. As a result the sample is poor, but indicative of the reception. The results are summarized in Figure 13. Most people found it interesting and stimulating, as shown in Figure 13a. They agree that they have learned something new and that they wouldn't have found this information on their own (Figures 13b-c). The duration of the conversation was satisfying (Figure 13d).



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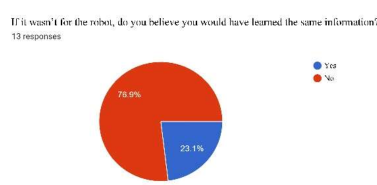

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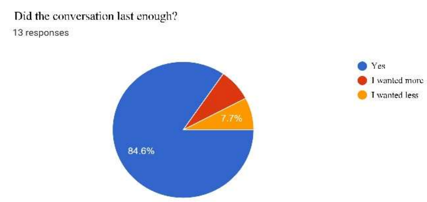

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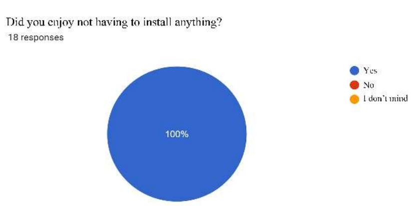
Figure 13. Evaluation of the "Discussion with the Robot" by adult visitors.

Similarly, we asked adults to rate the mobile app. The results are presented in Figure 14. 18 visitors participated in the questionnaire. They agree that the app was easy to use and convenient that they didn't have to install anything in their smartphones (Figures 14a-b). What is interesting is that 50% of the visitors prefers a software guide than a human guide; a result that perhaps needs to be verified by a larger sample and possibly shows that a visitor perhaps 1) feels more comfortable with a non-human guide or/and 2) wishes to adopt/select one's own pace when visiting an exhibition.



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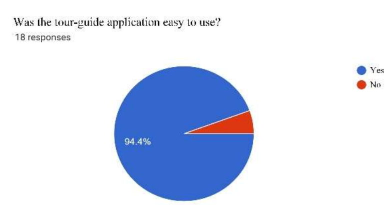

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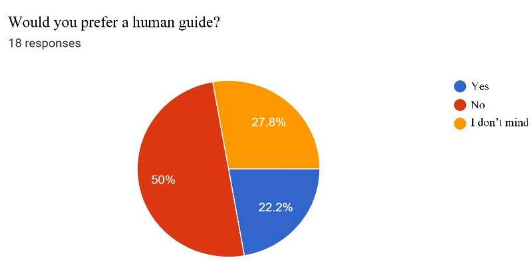

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Figure 14. Evaluation of the tour application.

B. Impact on the Labor Market

The advent of new technologies in culture are expected to have an impact on labor market. A clear indication was given in Figure 14c. Digital guided tours are expected to have an impact on physical-guides.

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However, such tours exist, in different forms, the last 3 decades. Therefore, it seems that some people prefer a human-guide, while others opt for the digital world. Artificial Intelligence, with its latest updates exhibited in large-language model-based chatbots, will possibly affect museum's personnel; tasks like information to visitors or monitoring could perhaps be addressed by technology. It seems reasonable to predict a reduction of museum's personnel; at least people related to the monitoring and safe-guarding of the museum.

On the other hand, support for the new digital systems, necessitates the recruitment of IT personnel in museums, capable to understand, administer and update such systems. At least, this is the case in the systems shown in this paper. Part of the income from the new applications (location-based guided tour, robot-rental) is spent on new personnel, specialized in Information technology.

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C. GDPR Related Measures

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The technology developed and applied in the museum is able to keep track of the locations of visitors and museum's personnel or more precisely, keep track of their digital twins; i.e. the RFID tags associated with them. However, visitors are and remain uknown. The tag is not associated with any visitor. It simply indicates the existence and movement of A (random) visitor. The statistics are not associated with anyone in specific. In fact the same tag is re-used, as shown in Figure 15. A visitor hangs the tag to his neck, in order to enjoy position-specific guided-tour and then returns the tag at the entrance. The tag is the key for localization.

As for the personnel, usage of RFID tags is optional to the museum's personnel. The system has been designed to monitor movements of exhibits and support "prior" labor-work carried out by such personnel (they had to take notes for such necessary movements of artifacts). So, only personnel, associated with these movement of artifacts is forced to use RFID tags, only during such movements. Related personnel has embraced the technology, as it has simplified related work; information related to each movement is automatically stored in the database, while personnel simply writes a short text, describing the reason for the movement (this text is stored and accompanies the artifact in its digital history).

Figure 15. The same RFID badge is re-used for many visitors, ensuring the anonymity of each

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C. Concluding Remarks

In this paper, we have summarized the outcome of the project "CultureID", where new technologies - mainly RFID, robotics and AI - were combined to improve the experience of visitors and facilitate the work of personnel in the Archaeological Museum of Thessaloniki. A location dependent guided tour, discussion with a prototype social robot and treasure-games for children represent some of the outcomes of the project to enliven the visitors' experience in the museum. Tracking of antiquities, personnel and visitors are the main benefits for the museum's administration and stuff, since they improve and facilitate everyday tasks.

Web Links

CultureId – Project. Link: https://cultureid.web.auth.gr/ (accessed October 14, 2022)
Use of RFID in the Met Museum, New York. Link: https://www.rfidjournal.com/nycs-metropolitan-museum-of-art-adopts-rfid (accessed April 5, 2023)
National Taiwan Museum of Fine Art Adopts Active-Passive RFID Solution. Link: http://fareastsun.com/News/news-0004.html (accessed April 5, 2023)
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