Introduction

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).

~~Furthermore,~~ At the same time the use of social-robots ~~are~~is increasing~~ly~~ ~~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. An overview of social robotics and their potential for museums is given in (Hellou et al. 2022).

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, r~~Restoration processes as well as the transfer of ~~ancient~~ artifacts for various purposes (e.g. analyses, study, temporary~~l~~ exhibitions etc.) are automatically triggered and stored in the Museum's database, while statistics ~~with respect to~~ on the visitors' movement and areas of interests are can also be generated. As for the visitors themselves, they can ~~enjoy~~ access guided-tours in their smartphone~~, in the vicinity~~ tailoured to~~of~~ their current location in the museum based on the proximity~~, identified by~~ to the RFID ~~technology~~tags. They can ~~join~~take part in discussions with the robot around major exhibits of the museum. Younger visitors can 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.

Commented [GAP1]: suggestion: trigger an automatic event that is stored in the museums database

Commented [GAP2]: Section I is the next paragraph. Suggest this reference is not required, or should be expanded to provide an outline of Section II and III

Suggest keeping the comment of the tracking process would normally be done by pen or paper, but could move into section I perhaps

Section I. RFID technology

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, 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.

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' ~~re~~location 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.

Commented [GAP3]: suggest reordering. describe situation first followed by the aim. e.g. "the museum hosts... The primary aim of the current project..."

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:

- 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, p~~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 3, 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 4.

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.

Commented [GAP4]: Suggest rephrasing: This ensures a trace of the artefacts location at all times.

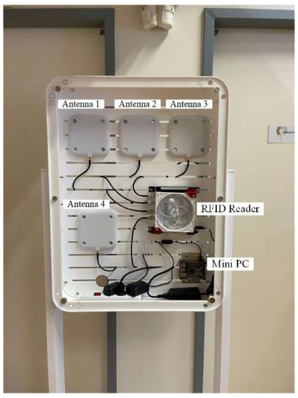


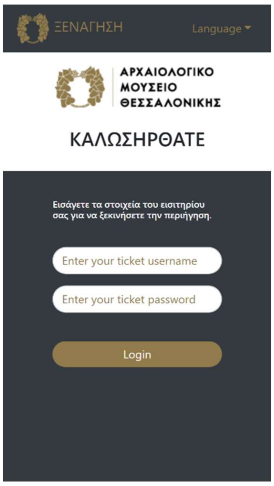
Figure 3 - RFID equipment is hidden inside plastic enclosures.

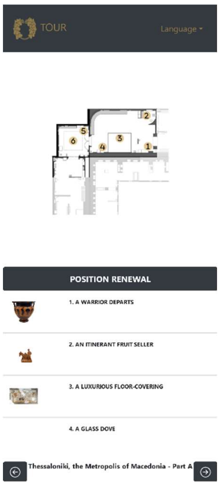
Figure 4 - RFID equipment, controlling the flow of visitors, personnel and artifacts, is distributed around the exhibitions areas, storage and restoration facilities of the museum.

B. Location dependent guided-tours

Our s~~S~~econd~~ly~~ aim was to provide location specific information within our web-based tour app.~~,~~To achieve this RFID tags were attached to each visitor's ticket. As a result, it ~~has become~~ is 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 web based guide, which is automatically updated based on their identified position inside the museum. The corresponding screenshots are shown in Figures 5-7.

Commented [GAP5]: Suggestion: include brief description in the body text of how the user enters the username/password from their ticket. It is clear in the figure, but a little ambiguous in the body text.





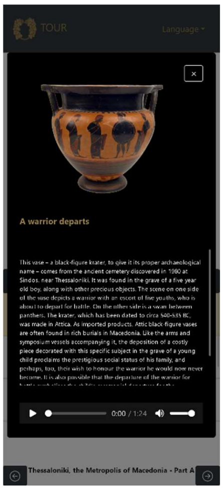


Figure 5 - Guided-tour. Login Screen

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

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

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C. Statistics of Interest

We have developed prototype methods to accurately trace the movement of people inside the museum which are presented in more detail (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, m~~Monitoring is not mapped to a specific individual, but is approximated~~ only used~~ for statistical analysis~~s~~; i.e. total-time spent at each artifact, heat maps of.... inside the museum, etc. The museum's management may select different statistics, filtered by the desired date. Such examples are shown in Figures 8-9.

Commented [GAP7]: Duplicate reference or missing a,b in date

Commented [GAP8]: suggestion: Perhaps stress that the ID is associated with the Ticket, not the visitor.

Commented [GAP9]: suggestion: specific what the heat maps are of visitor dwell time, visitor congregation size (i.e. bottlenecks)

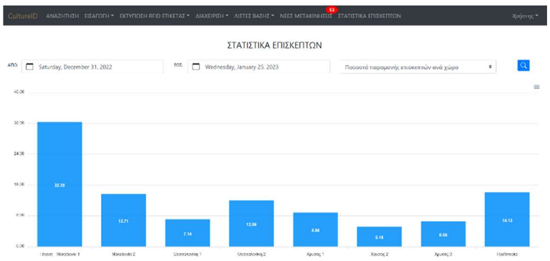

Figure 8 - Example of statistics of visitors' interest per exhibition area.

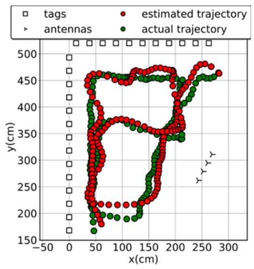

Figure 9 - Comparative result of the accomplished accuracy in tracking a visitor's trace by RFID technology inside the museum vs. one's actual trace [3].

Section III. 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. The corresponding actual map is shown in Figure 12 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.
- 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 and Figure 12. 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.
- 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.

Commented [GAP10]: Is this limited to specific languages?

- 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, a projector for output on a larger area, microphones and speakers for audio interaction and an RFID reader that allows it to interact with RFID-tagged exhibits and visitors.

Commented [GAP11]: Question: does this provide haptic feedback (buzzing, shaking, bump relief)? if not, suggest using different terminology.

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. The constructed robot is shown in Figure 15.

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. 16-18. Then, it poses questions. The answer for each question is related to the museum’s artifacts in the surrounding area.

Visitors are also 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 19-21, (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”.

Commented [GAP12]: suggestion: perhaps explain where the visitor can get access to the RFID reader - do they collect it from the desk when they get the ticket or are they available around the museum? This would help differentiate this description from robot. It may be worth moving this paragraph. below figure 18 and combining with the final paragraph.

Commented [GAP13]: duplicate reference, or missing a,b,c disambiguating

Commented [GAP14]: Suggestion: combine into single figure with sub reference a,b,c

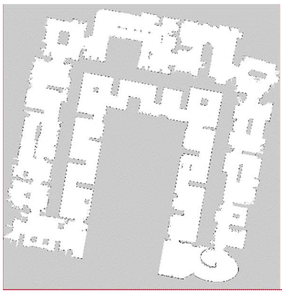

Figure 10 - Museum’s map, created by the robot’s sensors.

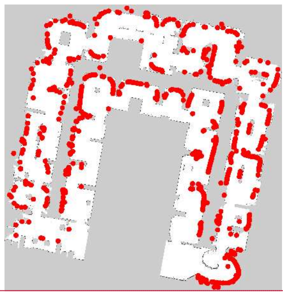

Figure 11 - The robot has identified and 3D-localized all RFID-tagged items inside the exhibition, thanks to prototype methods developed by the team.

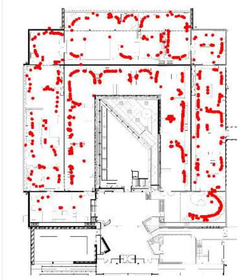

Figure 12 - The positions of the RFID-tagged exhibits have been updated in the museum’s map.

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

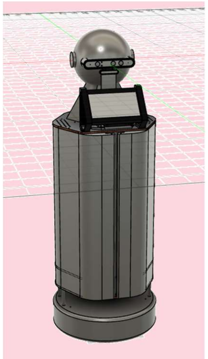

Figure 14 - The robot, during the design process.

Figure 15 - The constructed robot, outside the museum.

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

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

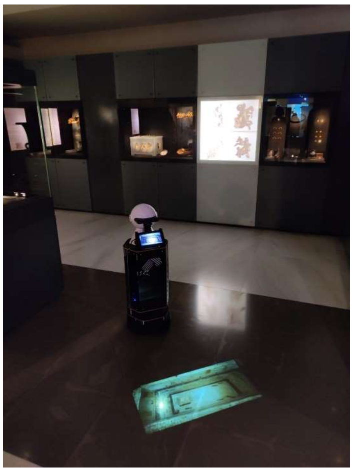

Figure 18 - The screen is also projected on the floor for better visualization of the information.

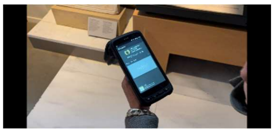

Figure 20 - The portable reader "guides" the "player"

Figure 21 - The "player" has reached the destination. One

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

to the correct area, through RFID technology.

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.

Commented [GAP16]: Suggestion: expand what is meant by machine learning algorithms here.

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

Section IV. Conclusion

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.

Commented [GAP17]: Suggest further discussion on the evaluation of this part of the project (performed, or planned is good too) or emphasising the prototype status if this is more appropriate for the current stage of the project.

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)

RFID in the National Gallery of Singapore. Link: https://www.nationalgallery.sg/magazine/how-do-we-tag-and-track-artworks (accessed April 5, 2023)

RFID Tags Enhance Museum Experiences and Back-End Support. Link: https://biztechmagazine.com/article/2019/10/rfid-tags-enhance-museum-experiences-and-back-end-support (accessed April 5, 2023)

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Let a Robot Be Your Museum Tour Guide. Link: https://www.nytimes.com/2017/03/14/arts/design/museums-experiment-with-robots-as-guides.html (accessed April 5, 2023)

Robot – demo. Link: https://www.youtube.com/watch?v=h4HmPYuXliQ (accessed October 14, 2022)

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