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The Open Cybernetics & Systemics Journal

RESEARCH ARTICLE

Promoting Industrial Cultural Heritage by Augmented Reality: Application and Assessment

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Abstract:

Backgrund:

Recent improvements of augmented reality technologies have boosted the design and the development of new solutions to support the user when visiting cultural sites. Each kind of multimedia information can be conveyed to the user in a new and intriguing way. On the other hand, a model to evaluate this kind of AR solutions for cultural heritage still misses.

Objective:

This paper aims to bridge the gap between applications and assessment by proposing a multivariate evaluation model and its application for an Android mobile augmented reality application designed to support the user during the visit of the historical industrial site of Carpano in Turin, Italy. This site is now a museum that keeps alive the memory of antique procedures and industrial machineries.

Method:

The proposed assessment model is based on a star like representation, which is often used to denote multivariate models; the length of each ray denotes the value of the corresponding variate. A three-level scale has been chosen for the proposed star-like representation: full length corresponds to the high-maximum level, medium length corresponds to the fair-average level and short length corresponds to the poor-null level.

Results:

The proposed AR application has been used by 13 people who, at the end of the experience, filled a questionnaire. Subjective feedbacks allowed us to evaluate the application usability. Moreover, the multivariate evaluation model has been applied to the AR application, thus outlining advantages and drawbacks.

Conclusion:

The presented multivariate evaluation model considers several different elements that can have an impact on the user experience; it also takes into account the coherence of the multimedia material used to augment the visit, as well as the impact of different thematic routes, is assessed.

Keywords: Augmented reality, Cultural heritage, Industrial architecture and heritage, Assessment model, Star-like representation.

1. INTRODUCTION

Augmented Reality (AR) technologies have been profitably used in different sectors such as medicine, industry, entertainment, military, tourism, education and so on [1 - 3]. Cultural heritage also strongly took advantage of a new

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and intriguing way to enhance the user experience in (cultural) tourism activities. AR allows to augment the reality by a set of computer-generated assets such as textual messages, images, videos, audio clips and 3D animated models. In other words, AR is an intermediate dimension between the reality and the virtuality (where the user can see only synthetic elements) [4]. Often, the term Mixed Reality (MR) is also used; in this case, the user is able to interact with computer-generated contents (*e.g.*, with 3D models).

From a technological point of view, an AR system is based on three different blocks: a tracking system, an asset/scene generator and a combiner [5]. The tracking system can be implemented by different technologies but, basically, it aims to clearly identify a real object in the scene; this detection step allows to compute the coordinate of the camera that is framing the scene with respect to the tracked object. The camera can be worn by the user when Head Mounted Devices (HMDs) are used or kept in hand when the AR application runs on smartphones and tablets. Different devices support different AR paradigms: HMDs support the see-through paradigm, whereas personal devices support the hand-held paradigm. When the coordinate of the camera with respect to the tracked object has been computed, assets can be generated in order to be correctly aligned with the real world. This is an issue when 3D static or animated models have to be overlapped to real elements. This step is performed by the asset/scene generator. Finally, the combiner overlaps assets to the user view by acting in different ways according to the used AR paradigm.

Tourism and cultural heritage can benefit AR, as a lot of additional information can be conveyed to the user in a very exciting and intuitive way [6 - 8]. Moreover, users can freely move through the site they are visiting without space and time constraints. Each kind of multimedia information can be managed and virtual reconstructions, as well as 3D animations, can be overlapped to the object the user is interested in.

Although several efforts have been devoted to investigate the application of AR to cultural heritage (see Section 2), a model to define what an AR system should provide to efficiently support cultural heritage still misses. This paper focuses on the identification of criteria for the evaluation of an AR cultural heritage software and proposes the application of this multivariate evaluation model to an AR Android application for the promotion of an industrial cultural site: the Carpano museum in Turin, Italy.

This paper is organized as follows: Section 2 reviews main works known in the literature concerning the application of AR to cultural and industrial cultural heritage, Section 3 presents the proposed multivariate model, Section 4 describes the AR application and Section 5 shows tests and results collected by asking 13 people to use the application inside the museum.

2. AUGMENTED CULTURAL HERITAGE

The union between augmented reality and cultural heritage can be dated back at the end of the last century when a new generation of personal devices enabled AR guides to be used in real contexts.

Advantages of AR for cultural heritage are manifold: a higher level of user engagement can be obtained, cultural spaces can be used in a more functional and complete way, more multimedia information can be conveyed to the user in real time and so on. Moreover, two key advantages have to be considered: (1) the user moves in the real world and the only assets to be generated (2) the users are not, in general, affected by motion sickness when AR applications are used for long time periods.

In order to take advantage of AR technologies, several museums and art galleries decided to provide users augmented visits. Some works can be considered as pioneers of this discipline [9 - 11] and the concept of Mobile Augmented Reality (MAR) has been evolving quickly since the first prototype of Archeoguide. Then, more sophisticated and powerful systems have been proposed; it is worthwhile to cite: PRISMA [12], MARCH [13] (based on smartphones), iTACITUS [14] (based on Ultra Mobile PCs), ARtSENSE [15] (an example of user-centered application) and others [16 - 19].

There is also an example of enjoyable exhibition just only by an AR application [20]: on October 2010, Sander Veenhof e Mark Skwarek sets up a completely digital event at the Museum of Modern Art (MoMA) in New York.

The above-mentioned examples of union between AR and cultural heritage tackled each issue in a very well defined way. In the beginning, a lot of efforts were devoted to overcome technological gaps (the first devices were portable but a free and user-friendly mobility has been reached only with the advent of smartphones and tablets [21]); then, tracking issues were considered. Outdoor sites can benefit from GPS localization [22], but GPS-denied environments need alternative solutions [23]. Technologies have been developed to support both computer vision and wireless localization

techniques. In general, these techniques might need a lot of computational power, thus requiring hardware improvements (also in terms of battery duration and network connectivity). More comfortable and usable devices have been also introduced; lightweight HMDs now allow users to enjoy the visit without keeping any device in their hands and the interaction with the AR application is based on more intuitive and natural paradigms (*e.g.*, voice and gestures). Successive works also focused on more attractive game logics (*e.g.*, [24]). AR software for cultural heritage has been designed as edutainment applications with the aim to enhance the level of engagement, thus involving the user in more sophisticated and challenging activities than the "simple" visit (*e.g.*, [25]). Finally, a lot of works known in the literature address the implementation of an AR application tailored for a specific use case [26 - 29]. A recent taxonomy, based on activity, has been used to classify 86 AR applications for cultural heritage [30].

This paper is not only another AR application for cultural heritage; infact, this work aims to bridge the gap between design and evaluation. A multivariate assessment model is proposed, which identifies the main variates to be considered when designing both the application and the augmented contents. An application to support the user in visiting the Carpano museum has also been implemented and its compliance with the proposed model is shown.

Together with the design of the app, the identification of data and information to be conveyed was not limited to draw on bibliographic material or texts elaborated for other purposes, but it has dealt with the analysis right away in the logic of Public History [31], of which archives and museums are the natural fields for experimentation and application. To question the sources starting from the assumptions of a story "for the public", suitable not only for the dissemination of information on several levels, but also as a meta-tool in the broadest sense of the term - project, valorization, creation and strengthening of community identities, a sense of belonging and sharing-, involves a method of research, comparison and interpretation of the documentary material that needs some corrections. The historical investigation in the form of a digital history [32] does not substantially change the research methodology but requires to foresee a variety of queries not usual in traditional research. The collaboration between historians and software developers needs a synthesis in communication (buttons, actions, on-line information) and documentary material; therefore, a "mediator" professional between the humanistic and technical cultures [33], that have to collaborate by using a design thinking approach, confirming, once again, the cultural and technological transformations in progress and opening the way to new and fruitful collaborations, is necessary for this kind of project.

3. THE PROPOSED MULTIVARIATE MODEL

The proposed multivariate evaluation model considers 14 variates and it is shown as a star-like representation in Fig. (**1**). Star-like representations are often used to denote multivariate models [34]; the length of each ray denotes the value of the corresponding variate. A three-level scale has been chosen for the proposed star-like representation: full length corresponds to the high-maximum level, medium length corresponds to the fair-average level and short length corresponds to the poor-null, level. Meanings of the 14 variates are:
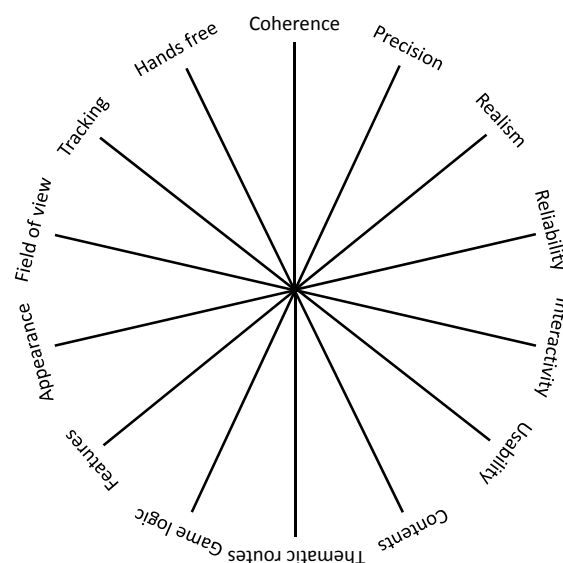

Fig. (1). A star-like representation of the proposed multivariate model.

- **Coherence**: It represents the congruence of augmented information with historical information. It does depend on historical sources available to gather the material to be presented, in different forms, to the user.
- **Precision**: It represents the capability to correctly align augmented contents; in particular, 3D static and animated models. This variate is strongly related both to the tracking system and to the environmental conditions.
- **Realism**: It defines the quality of graphics assets such as images, videos, and 3D models. This variate is related to the coherence of information sources.
- **Reliability**: It represents the probability of the AR system to work as expected, without any kind of "failure". This variate is related to HW/SW technologies.
- **Interactivity**: It represents the degree of interaction between user and system; when the user is able to interact with 3D contents, it means that virtual assets can be anchored in the space and some forms of interaction (voice, gesture, touch, *etc.*) are provided.
- **Usability**: It presents the capability of the user in interacting with the system in a satisfactory and enjoyable way. Several of the other variates can affect the usability; moreover, the usability can be measured by standard questionnaires.
- **Contents**: Number and kind of contents can strongly affect the user experience. Contents have to be detailed and intrigued but a redundancy of contents might lead to an excessive cognitive workload.
- **Thematic routes**: It represents the possibility to arrange contents in different cultural paths, thus providing the user the possibility to customize the visit according to personal interests.
- **Game logic**: It is well known that education and gaming can be profitably mixed together in order to engage the user much more than a simple multimedia guide could do. The game logic has to be carefully designed in order to obtain a high engagement level.
- **Features**: This variate represents the system functionality. Features should be easy to use and they are to provide a real added value to the user.
- **Appearance**: It is related to the interface of the application: the choice of colors, images, buttons, menus and so on is the starting point to create an interface that should be coherent with the visual identity of the site to be visited.
- **Field of view (FoV)**: It represents the part of the scene visible from the user augmented by the application. Narrow FoVs do not allow the user to see large objects (*e.g.*, industrial machineries) from a close point of view.
- **Tracking**: It is the method with which the AR application identify known elements in the scene framed by the camera. Two basic approaches are used: marker and marker-less; both of them have advantages and drawbacks.
- **Hands-free**: It represents the possibility of users to move around the site without keeping any kind of device in their hands. Usually, this variate can be maximized only by wearing HMD devices.

4. THE PROPOSED APPLICATION

The application has been developed by the AR framework Vuforia [35] as it supports a multi-platform deployment of applications and is strictly integrated with the Unity game engine [36], which allows developers to easily manage 2D and 3D animated contents. In particular, the deployed application has been optimized for Android devices. The architecture of the proposed application is shown in Fig. (**2**).

Due to the indoor illumination of the Carpano museum (completely artificial and quite feeble), it has been chosen to select a tracking approach based on the marker. In this way, a stable tracking can be obtained also in poor lighting conditions by placing small targets in the environments. Moreover, marker tracking is almost independent of the camera position, thus allowing the user to move around virtual (3D) assets without limitation. Each thematic route (see Section 4.1) is composed of four markers. As the number of images to be tracked is limited, images have been stored in the internal DB of the application (Vuforia allows to store images also in the cloud), thus making the tracking step faster and independent of Internet connections. The drawback of this choice is the dimension of the application to be deployed for a personal device, but this is an issue only when thousand or more images have to be recognized.

From a logical point of view, the application is split into four scenes; three of them have been implementing exclusively by Unity and one by the elements (AR camera, image target, scripts, etc.) provided by Vuforia.
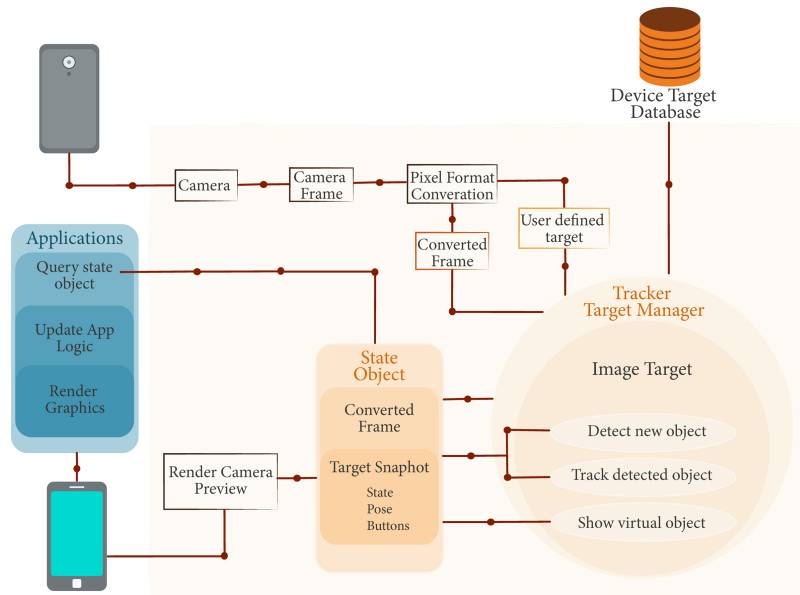
Fig. (2). Architecture of the proposed application.

The application is named ARCarpano and the first scene is the main menu (see Fig. **3** – left). The main menu shows the logo and three buttons; basically, it presents the application features: searching for contents (the big button name "Inizia"), reading the application guide and reading application credits.
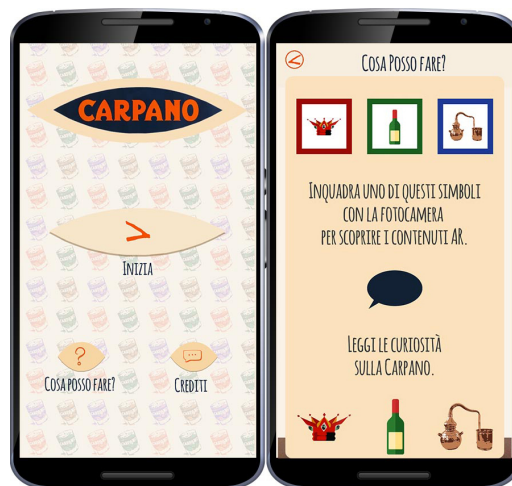

Fig. (3). The main menu (left) and the application guide (right).

The user guide (see Fig. **3** - right) is a panel that shows a sort of manual explaining the meaning of each marker/image to be searched in the environment; this panel can be browsed vertically by a slider. The credit scene exhibits the same structure as the user guide.

When the user presses the button "Inizia" (that means "Start"), the application activates the device camera and searches for a target stored in the internal DB. Meanwhile, new buttons appear at the bottom of the application. When no marker is recognized, two buttons appear one to go back to the main menu and the other one to take a snapshot. On the other hand, a third button can appear (see Fig. **4**) when a marker is recognized. Assets (images, videos, 3D models, *etc*.) appear when a marker is tracked and a textual description can be available through the third central button of Fig. (**4**).

Fig. (4). The interface appearing at the bottom of the application.

This scene to search for content has been implemented by a Unity canvas and an image target has been added for each asset; then, image targets have been associated with the markers stored in the internal DB. Static and animated models (with materials and textures), images and videos have been associated with the markers. Fig. (**5**) shows some examples of assets: the left picture represents an advertising billboard, the central image represents a static model designed by Armando Testa (Punt e Mes) for an advertising campaign and the right image represents a 3D animation of King Carpano (a virtual character used for advertising).
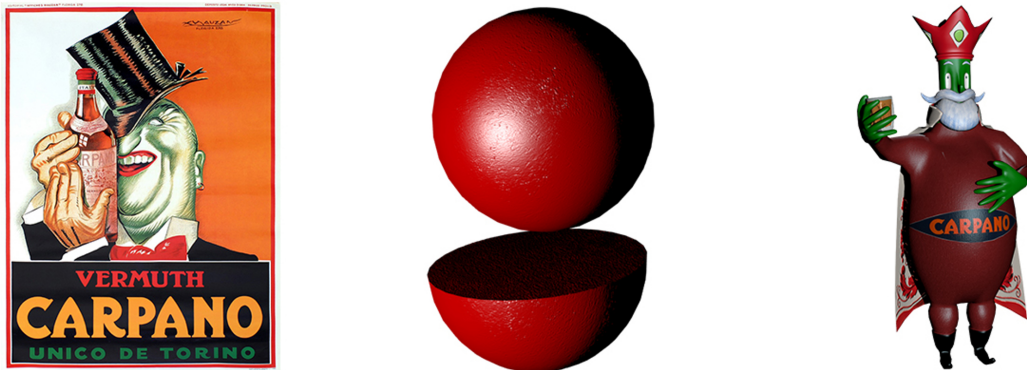
Fig. (5). Examples of assets.

The button to take a snapshot creates an image in PNG format stored in the external memory of the device. When a video clip has to be played, buttons related to textual descript and snapshot are replaced by two other buttons enabling the user to pause and play the video.

4.1. Thematic Routes

A detailed historical analysis about neglected industrial sites related to wine-making and confectionery products in Turin has been performed; several sites can be considered, but a few of them can be visited for tourism as many plants are closed and others have been converted to private buildings. The Carpano distillery placed in *via* Nizza 244, Turin, has been selected; this building is now the location for the shopping center Eataly. The whole building is extremely vast and the testing field has been restricted to the Carpano museum at the first floor of the building. The museum is organized in four rooms and is separated from the shopping center. The main thematic routes have been identified and each path is denoted by a different color:

- Historical path (green): This path aims to present the history of the Carpano brand. Markers represent different bottles the user will find in the four rooms.
- Artistic path (red): With this path, the user is introduced to the communication strategies (*e.g.*, TV spots and advertising billboards) used to promote the Carpano's products. Markers represent most significant images of advertising campaigns.
- Industrial path (blue): This path is strictly related to the Vermouth production. Old receipts are shown, as well as

the industrial machineries and barrels are presented. Markers represent the steps of the alcoholic spirit manufacturing.

Markers used to denote the different routes are shown in Fig. (**6**).

Fig. (6). Examples of markers related to the three thematic routes: green-historical, red-artistic and blue-industrial.

5. TESTS AND RESULT ANALYSIS

A set of volunteers (13 people) have tested the application inside the Carpano museum. Although 13 people are not enough to provide an exhaustive statistical analysis, they are sufficient both to test the application functionalities and to evaluate the potentialities of the proposed approach. Each person has been briefly trained individually in order to explain the application interface and the age of testers ranged from 26 to 62 years. At the end of the augmented tour, people were asked to fill a questionnaire. The first questions are aimed to gather data about age, gender and the degree of confidence in using smartphone and tablet; the familiarity with AR applications was also asked (only the 38,5% had already used AR software).

For the other questions, users had to rank from 1 (completely disagree) to 5 (completely agree) a set of statements. Fig. (**7**) shows the answer to the question about the clarity of the interface; inside each bar, the number of people and the percentage are reported. As it can be noticed, just one person was not satisfied with this issue, whereas all the other users were satisfied.
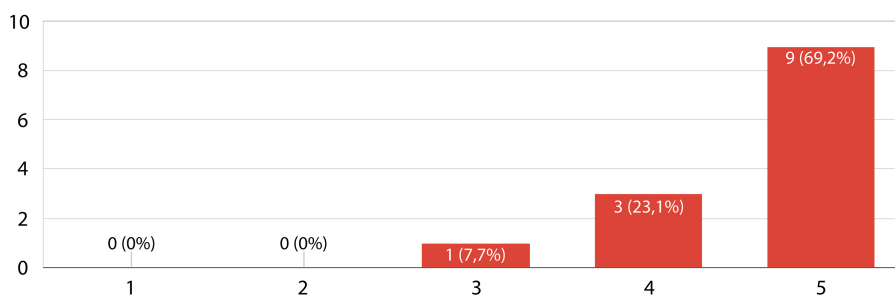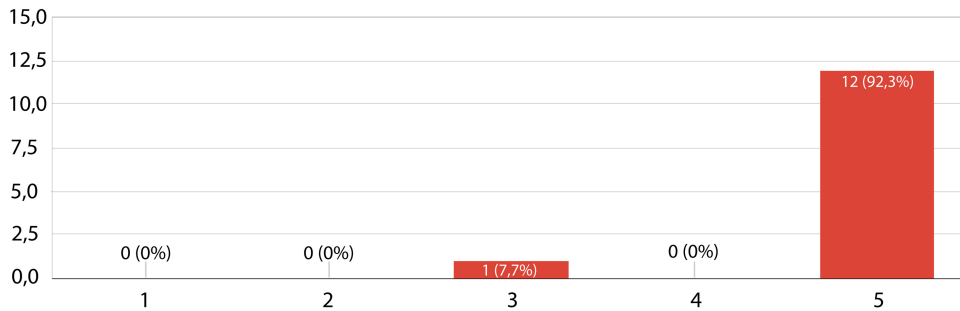

Fig. (7). Bar chart of the answer about the clarity of the interface.

More in the detail, a question was devoted to investigate the interface from the point of view of shape and color of graphics elements; Fig. (**8**) shows the bar chart of the question about the intuitiveness of graphics elements (*e.g.* the 3 buttons the user can see at the bottom of the application). Among all the users, one was completely aware of the meaning of these 3 buttons and all testers were able to go back to the main menu without any problem.

Fig. (8). Bar chart of the answer about the intuitiveness of graphics elements.

The best part of users (92,3%) appreciated the possibility to take a snapshot of the augmented environment. Moreover, all testers enjoyed computer-generated assets and considered textual information essential for the promotion of the industrial cultural heritage.

Finally, some users suggested to add a sort of map able to display the position of significant contents placed in an area also larger than the single museum. In this way, it should be possible to follow more easily a thematic route that involves different sites on a city scale.

5.1. Mapping Of The Application To The Proposed Model

This Section aims to map the proposed application onto the multivariate evaluation model presented in Section 3. Each variate is considered and evaluated (see Fig. **9**):
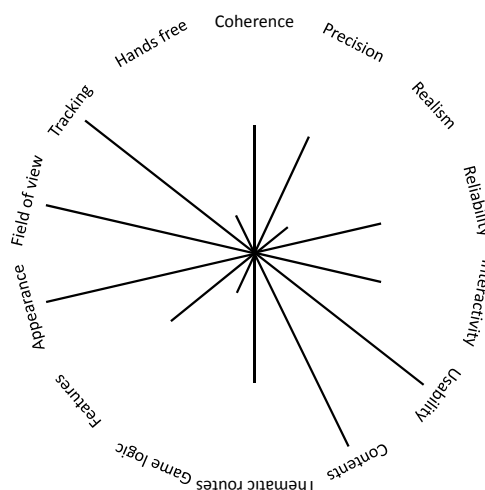
Fig. (9). Mapping of the application onto the multivariate evaluation model.

- **Coherence**: This variate is related to the available historical sources and, for the selected case use, some materials are available (*e.g.*, photos, illustration, recipes, description, and so on) but miss other information. For instance, there are not enough details to accurately design CAD models of the industrial machineries used to produce the Vermouth.
- **Precision**: In general, this is not an issue for this kind of AR applications, whereas precision might be mandatory for medicine or military applications. On the other hand, as a marker, tracking technique has been selected. The precision is quite good, but it is affected by the poor lighting condition inside the museum.
- **Realism**: This variate is limited both to the impossibility to accurately reconstruct some assets (*e.g.* the industrial machineries) and to the limited computational power of the mobile device. Moreover, a hand-held device is not able to provide users a sense of "immersion" in the augmented environment.
- **Reliability**: Both the AR framework used to develop the application and the selected device does not manifest any particular problem in terms of reliability. On the other hand, some problems can arise when the device memory is not sufficient to cope with the computer generated assets (*e.g.*, high-resolution 3D models).

- **Interactivity**: The user can interact with the application to accomplish some basic tasks, but it is not possible to interact with 3D virtual contents. For this reason, the level of interactivity is average.
- **Usability**: This variate has been measured by a questionnaire and very satisfactory feedback has been received.
- **Contents**: The application can provide each kind of computer generated asset: textual description, videos, audio clips and 3D static-animated models. This variate is therefore complete.
- **Thematic routes**: Three different thematic paths are provided, which cover the historical, artistic and industrial areas. On the other hand, other routes (*e.g.*, considering architectural issues) could be considered.
- **Game logic**: The game logic is quite simple and basically concerns the research of the next marker along the thematic route.
- **Features**: The application provides basic features related to the selection of the asset and an extra feature enabling the user to take snapshots of the augmented environment.
- **Appearance**: The "style" of the application has been carefully designed. The main goal was to recall the old Carpano's visual identity; therefore, colors, the logo, used fonts, and so on have been selected after a deep design study.
- **Field of view (FoV)**: As a smartphone-tablet device has been selected, the available FoV is similar to the one provided by a wide-angle lens.
- **Tracking**: A marker approach has been preferred. Small markers have been placed in the museum and this provides a quite precise and stable tracking. This also mitigates issues related to the poor lighting conditions inside the museum.
- **Hands-free**: This variate is low as the personal hand-held device has been considered.

CONCLUSION

This paper investigates issues related to the design and the development of AR applications to support (industrial) cultural heritage. A multivariate evaluation model is presented; it considers several different elements that can impact on the user experience. Moreover, the proposed model also takes into account the coherence of the multimedia material used to augment the visit, as well as the impact of different thematic routes, is assessed.

An AR application to support users during the visit of the Carpano museum in Turin, Italy, is also presented. This mobile application implements three thematic paths in order to provide detailed information about the industrial, artistic and historical elements related to an industrial site now converted to a museum. The application has been tested by 13 heterogeneous users, who filled a questionnaire used to gather subjective evaluations about the usability of the application. Moreover, the multivariate model has been applied to the AR application, thus outlining qualities and lacks.

Future work will be aimed to validate the proposed model with other use cases, possibly considering also AR applications deployed for HMD devices, such as the Microsoft Hololens, which provide different levels of mobility, interaction, sense of immersion and realism.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEGEMENTS

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