Outdoors Mobile Augmented Reality Application Visualizing 3D Reconstructed Historical Monuments

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Abstract: We present a mobile Augmented Reality (AR) tourist guide to be utilized while walking around cultural heritage sites located in the Old town of the city of Chania, Crete, Greece. Instead of the traditional static images or text presented by mobile, location-aware tourist guides, the main focus is to seamlessly and transparently superimpose geo-located 3D reconstructions of historical buildings, in their past state, onto the real world, while users hold their consumer grade mobile phones walking on-site, without markers placed onto the buildings, offering a Mobile Augmented Reality experience. we feature three monuments; e.g., the 'GialiTzamisi', an Ottoman mosque; part of the south side of a Byzantine Wall and the 'Saint Rocco' Venetian chapel. Advances in mobile technology have brought AR to the public by utilizing the camera, GPS and inertial sensors present in modern smart phones. Technical challenges such as accurate registration of 3D and real world, in outdoors settings, have prevented AR becoming main stream. We tested commercial AR frameworks and built a mobile AR app which offers users, while visiting these monuments in the challenging outdoors environment, a virtual reconstruction displaying the monument in its past state superimposed onto the real world. Position tracking is based on the mobile phone's GPS and inertial sensors. The users explore interest areas and unlock historical information, earning points. By combining AR technologies with location-aware, gamified and social aspects, we enhance interaction with cultural heritage sites.

1 INTRODUCTION

AR is the act of superimposing digital artefacts on real environments. In contrast to Virtual Reality where the user is immersed in a completely synthetic environment, AR aims to digitally complement reality (Azuma et al. 2001, Zhou et al., 2018). In comparison to older systems that used a combination of cumbersome hardware and software, recent advances in mobile technology has led to an integrated platform including GPS functionality, ideal for the development of AR experiences, often referred to as Mobile AR (MAR). Applications in the fields of medical visualization, maintenance/repair, annotation, robot path planning and entertainment enrich the world with information the users cannot directly detect with their own senses (Nagakura et al., 2014; Niedmermair et al., 2011; Kutter et al., 2008, Ragia et al., 2015).

In this paper, we present the design and implementation of a MAR digital guide application for Android devices, that provides on-site 3D visualisation and reconstructions of historical buildings in the Old Town of Chania, Crete, Greece. 3D imagery of how archaeological sites existed in the past, are superimposed over their real-world equivalent, as part of a smart AR tourist guide. Instead of the traditional static images or text presented by mobile, location-aware tourist guides, we aim to enrich the sightseeing experience by providing 3D imagery visualising the past glory of these sites in the context of their real surroundings, seamlessly, without markers placed onto the buildings, offering a MAR personalized, gamified experience, showcasing the city's cultural wealth.

The mobile AR application features a multimedia database that holds records of various monuments. The database also stores the users' documentation of their visits and interactions in the areas of interest. User requirements gathering and AR development while located in the challenging outdoors environment of a city, pose significant technical as well as user interaction challenges. Reliable position and pose tracking is paramount so that 3D content is

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accurately superimposed on real settings, at the exact position required and is one of the major technical problems of AR technologies.

Our system features a geo-location and sensor approach which compared to optical tracking techniques allows for free user movement throughout the site, independent of changes in the building's structure. The MAR application proposed provides an easily extendable platform for future additions of digital content requiring a minimal amount of development and technical expertise.The goal is to provide a complete and operational AR experience to the end-user by tackling AR technical challenges efficiently, as well as offering insight for future development in similar scenarios.

1.1 Motivation

Since the Neolithic era, the city of Chania has faced many conquerors and the influences of many civilizations through time. Byzantine, Arabic, Venetian and Ottoman characteristics are evident around the cultural center of the town clustered towards the old Venetian Harbor. In order to provide the tourist with a view of the past, based on cutting-edge AR technologies, we designed a historical route throughout the city consisting of a selection of historical buildings, to be digitally reconstructed and presented in their past state through an AR paradigm. The final selection includes three monuments that represent key historical periods of the Town of Chania (Figure 1).

The Glass Mosque is located in the Venetian Harbor of Chania and it is the first mosque built in Crete and the only surviving in the City dating from the second half of the 17th Century. The mosque is a jewel of Islamic art in the Renaissance and featured a small but picturesque minaret demolished in 1920 or in 1939. *The Saint Rocco temple* is a Venetian chapelon that consists of two different forms of vaulted roof aisles. Although the southernmost part is preserved in good condition, the northern and oldest one has had its exterior painted over, covering its stony façade, while a residential structure is built on top. *The Byzantine wall* was built over the old fortifications of the Chydonia settlement around the 6th and 7th century AD. Its outline is irregular with longitudinal axle from the East to the West, where its two central gates were located. The wall consists of rectilinear parts, interrupted by small oblong or polygonal towers many of which are now partly or completely demolished.

The scope of this work is to virtually restore partially or fully damaged buildings and structures on historic sites and enable visitors to see them integrated with their real environment, while using a sophisticated AR mobile tourist guide. We aim to deliver geo-located information to the users as well as calculate accurate registration positioning between the real-world monument and 3D digitisations, while users document their visits. By integrating digital maps and a location-aware experience we aim to urge the users to further investigate interest areas in the city of Chania, Crete, and uncover their underlining history by exploiting cutting edge AR mobile technologies.

Figure 1: The Glass Mosque (left), the Saint Rocco Temple (right), the Byzantine wall (middle).

1.2 Previous Work

AR has been utilized for a number of applications in cultural heritage. One of the initial MAR systems provided on-site help and AR reconstructions of the ruins of ancient Olympia, Greece (Vlahakis et al., 2001). The system utlilized a compass, a DGPS receiver and combined with live view images from a webcam, it obtained the user's location and orientation. Visitors carried a heavy backpack computer and wore a see-through Head Mounted Display (HMD) to display the digital content. The system was a cumbersome MAR unit not acceptable by today's standards. MARCH (Choudary et. al. 2009) was a MAR application developed in Symbian C++, running on a Nokia N95. The system made use of the phone's camera to detect images of cave engravings and overlay them using an image indicating ancient drawings. Although this was the first attempt of a real time MAR application without the use of grey-scale markers, the system still needed the placement of coloured patches at the corners of 2D images captured in caves and the experience was not tested in cave environments.

With the advent of mobile devices, more sophisticated AR experiences are made possible such as the one for the Bergen-Belsen memorial site, (Pacheco et. al. 2014), a former WWII concentration camp in northern Germany which was burned down after its liberation. The application integrated database interaction, reconstruction modelling and content presentation in a hand held device. Real time tracking was performed with the device's GPS and orientation sensors and navigation was conducted either via map or the camera. The system was superimposing the reconstructed building models on the phone's camera feed. Focusing more on the promotion of cultural heritage in outdoor settings, VisAge (Julier et al., 2016) was an application aiming to turn users into authors of stories and cultural histories in urban environments. The system featured an online portal where users could create their stories using routes through physical space. A story is a set of spatially distributed POIs (Points of Interest). Each POI has its own digital content consisting of images, text or audio. A viewing tool was developed for mobile tablets in Unity using Vuforia's tracking library to overlay the digital content in the real space. The users could follow routes in the city and experience new stories. Tracking was performed using feature detection algorithms from the camera's feed. As per any optical approach, content delivery is not guaranteed due to the lighting variations of the outdoor setting.

Further work in 3D reconstructions was shown in CityViewAR (Lee et al., 2012), a mobile outdoor AR application that was developed to allow people to explore destroyed buildings after the major earthquakes in Christchurch, New Zealand. Besides providing stories and pictures of the buildings, the main feature of the application is the ability to visualize 3D models of the buildings in AR, displayed on a map. Finally, a practical solution presented in (Hable et al., 2012) targeted guiding groups of visitors in noisy in-door environments, based on design decisions such as analogue audio transmission and reliably trackable AR markers. However, preparation of the environment with fiducials is time consuming and the supervision of the visits by experts is necessary to avoid accidents and interference with the working environment.

2 METHODOLOGY

We present a MAR application that besides offering geo-localised textual information concerning cultural sites to a visitor, it also superimposes location-aware 3D reconstructions of historical buildings, positioned exactly where the real-world monuments are located, displayed on visitors' Android mobile phone. The geo-location approach used for real-time tracking is based on sensors available to both high and low-end mobile phones eliminating hardware restrictions and allowing for easy integration of added historical buildings. It also offers the opportunity to visualize historical sites in non-intrusive ways without placing markers or patches on their walls. It also introduces gamified elements of cultural exploration.

The geo-location approach is adopted that employs the GPS and the inertial sensors of the device so that when the specific location of the actual monument is registered, then the 3D reconstruction of it would be displayed. Locations containing latitude and longitude information are received from the GPS while the accelerometer and geo-magnetic sensors are used to estimate the device pose in the earth's frame. A visual reconstruction is then matched to the user's position and viewing angle displaying the overlaid models on the mobile phone's screen. This implementation offers the most reliable registration of 3D content accurately superimposed on the real-world site, demanding less actions from the users, therefore, ensuring a robust and intuitive experience (Střeláket. al. 2016).

The preparation of the 3D models required the acquisition of historical information and the accurate depiction of them in scale with the real world. Due to the lack of accurate plots and outlines of the buildings, Lidar and DSM data were exported from Open Street Maps and used to create the final models. Designing for a mobile device means that limited processing power and the requirements of the AR technologies need to be taken into account. Complex geometries can impair performance so a low-poly, high-resolution texture approach was adopted in order to avoid frame rate drops. The final models are then processed through Google Sketch-up to geo-reference and position them onto the real world while looking at the screen of a mobile phone.

Digital maps and an AR camera displaying the interest areas were integrated to assist in navigation through the geo-located content. The client-server architecture ensures that personalised experiences are provided by storing information about user visits and progress. Changes in the server can be conducted without interfering with the mobile application allowing for an easily extendable platform where new monuments could be added as visiting areas. The monuments' information and assets are stored in a database and delivered to the mobile application in a location-request basis. The application was developed for Android in Java as well as employing the Wikitude Javascript API for the AR views. It features a local database based on SQLite cashing the downloaded content.

2.1 3D Modeling and Texturing

In order to record the past state of the selected monuments, old photographs, historical information and estimates from experts were utilized. The 3D models visualizing their past state are presented in real size superimposed over the real-world monument and must be in proportion with their surroundings. Therefore, accurate measurements of their structure are necessary. Due to the lack of schematics and plots, we relied on data derived from online mapping repositories which provide outlines and height. The outlines of the three monuments were acquired from Open Street Map (OSM). By selecting specific areas of the monuments on the map, we can then export an .osm file that contains the available information concerning that area, including building outlines and height, where available. This file is essentially an xml file including OSM raw data about roads, nodes, tags etc. The file is then imported into OSM2World, e.g., a Java application whose aim is to produce a 3D scene importing as input the underline data.

The modelling process was focused on preserving a low vertex count as complex geometry compromises interactive frame rate in systems of low processing power such as mobile phones. Complete 3D reconstructions of the selected monuments were created so that they completely overlap the real ones based on AR viewing. The most important aspect of this strategy is to keep the reconstructions in proportion. The final scale and size are defined in Google Sketch-up, while the final model is positioned in the world coordinate system. The Byzantine wall being the most abstracted, resulted in 422 vertexes. The Glass Mosque counts 7,614 and the Saint Rocco temple 4,919 vertexes.

Images captured from the real monuments on site were used as references. A diverse range of materials are assigned to different parts of the buildings. Due to the lack of information, the actual texture of the reconstructed parts is unknown so the aim is to more accurately represent the compositing material rather than the actual surface. The AR framework supports only a power of 2 .png or .jpeg single material texture map. That means that bumps, normal maps and multi-textures are not included. The materials that compose the entire texture set are baked into one image that will serve as the final texture. UV mapping is the process of unwrapping the 3D shape of the model into a 2D map. This map contains the coordinates of each vertex of the model placed on an image. Taking into account that the monuments will be displayed on a mobile phone screen in real size, high resolution textures were required. This raises the final size of the texture files, however, the process results in a high quality visual result (2048x2048 pixels).

2.2 Geo-Positioning

In order for the reconstructions to be accurately displayed, combined with real-time viewing of the real world, an initial transformation and rotation is applied. The models were exported in .dae format and imported into Google Sketch-up.

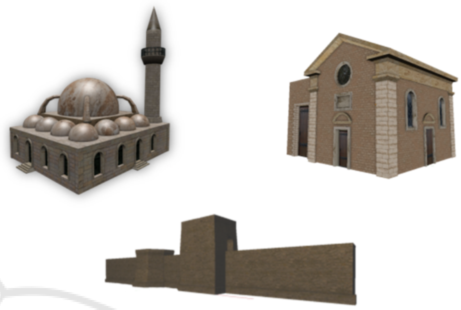

Figure 2: Final 3D models.

The area of the monuments provided by Google maps was projected on a ground plane. The monument is, then, positioned on its counterpart on the map. Given that the proportions of the monuments are in line, the final model is scaled to fit on the outlines. The location of the monument is then added to the file and provided to the framework. In order include the model in the AR framework, we export it to .fbx and use the provided 3D encoder to make a packaged version of the file together with the textures in the custom wt3 format. This file is, then, channelled to the MAR app.

3 AR SOLUTIONS

The most significant technical challenge of AR systems is the registration issue. The virtual objects and the real ones must be appropriately aligned in order to maintain the illusion of integrated presence. Registration in an AR system relies on the accurate computation of the user's position and pose as well as the location of the virtual objects. Focusing on MAR tracking is either conducted based on sensor-based implementations or computer vision techniques. While computer vision approaches seem to provide pixel perfect registration, anything that compromises the visibility between the user and the augmented area can result in the virtual scene jitter or collapse. In addition to this, adequate preparation of the environment needs to take place. While sensor approaches are more robust, limits in acquiring reliable data leads to low accuracy. The work proposed focuses on providing a complete MAR experience to the end-user. Commercial AR frameworks were employed, initially evaluating both optical and sensor-based approaches.

3.1 Optical Implementation

In computer vision implementations, the live feed from the camera is processed in real-time to identify points in space, known a priori to the system and estimate the user's position in the AR scene. These tracking methods require that scene images contain natural or intentionally placed features (fiducials) whose positions are known. Since we don't want to interfere with the monuments, placing fiducial markers in the scenes was out of the question so we relied on pictures and the natural features of the scenes. A basic application was developed in Unity employing the Vuforia plug-in to test the registration. The image recognition methods use "trackable targets" to be recognized in the real environment. The targets are images processed through natural feature detection algorithms to produce 2D point clouds of the detected features to later be identified by the mobile device in the camera's feed. When detected, pose and position estimations are available relative to the surfaces they correspond to. The denser the point clouds are, the better the estimate. This means that the initial images need to contain a large amount of detectable features. For real world buildings, these features most often represent window and door corners and intense changes in the texture, which do not provide a large enough number of features for the algorithm to track. Taking into account the lighting variations of outdoors, the sets of features provided to the system differed greatly from the actual scene and pose tracking was not achievable. Outdoors environments present very challenging conditions to such implementations. Building façades provided a limited amount of features and together with variations in lighting conditions, such a system would need a huge amount of images and training to reliably track the outdoor scene. Taking also into account the cramped environment of a touristic site, image recognition was not a realistic choice.

3.2 Sensor Implementation

Sensor approaches use long-range sensors and trackers that report the locations of the user and the surrounding objects in the environment. These tracking techniques do not require any preparations of the environment and their implementation relies on cheap sensors present in every modern smart phone. They require fewer actions by the users and ensure that the AR experience will be delivered independent of external conditions. The AR system is aware of the distance to the virtual objects, because that model is built into the system. The AR system may not know where the real objects are placed in the environment and is relying on a "sensed" view with no feedback on how close the two align. Specifically in MAR, modern devices are equipped with a variety of sensors able to provide position and pose estimations. In outdoor settings, the Assisted GPS allows for position tracking with an accuracy of up to 3 meters and for pose estimation, the system combines data from the accelerometer and geo-magnetic sensors. The accelerometer provides the orientation relative to the centre of the Earth and the geo-magnetic sensor to the North. By combining this information, an estimate of the device's orientation in the world coordinate system is provided. For this approach, we used the Wikitude's JavaScript API in combination with our own location strategy. The Wikitude JavaScript API was selected due to its robust results, licensing options, big community and customer service. The implementation includes the Android Location API and the Google Play Services Location API. For the later, the application creates a request, specifying location frequency and battery consumption priority. After it is sent out, location events are fired including information about latitude, longitude, altitude, accuracy and bearing. These are then provided to the AR activities to transform and scale the corresponding digital content on the screen.

4 SYSTEM ARCHITECTURE

4.1 Client-Server Implementation

One of the main challenges we faced in designing the proposed MAR application was the lack of established guidelines in the application and integration of AR technologies in outdoor heritage sites. The overall design of the system consists of two main parts: the mobile client and the server. The server facilitates a database developed in MYSQL which holds the records about the monuments (name, description, latitude, longitude etc.) and user specific information. The information is delivered to the mobile unit on a location request basis. The database is exposed to the users via a Rest-full Web-Service. A basic registration to the system is required. The functions provided include storing data about visits, marked places and the overall progress visualizing all sites in a specific area.

4.2 Mobile AR Application

The mobile application's architecture has been designed to be extendable and respond easily to changes in the underling model of the server. It is based on three main layers. The *Views layer* is where the interactions with the users take place. Together with the background location service they act as the main input points to the system. The events that take place are forwarded to the *Handling layer* which consists of two modules following the singleton pattern. The data handler is responsible for interaction with the local content and communicating with the views while the Rest Client is responsible for communicating with the Web Service. The *Model layer* consists of basic helper modules to parse the obtained JSON files and interact with the local database. The actions flow from the Views layer tothe lower components. Responding to a user event or a location update, a call is made to the Handling layer which will access the model to return the requested data.

The Handling layer is the most important of the three; all interactions, exchange of information and synchronization passes through this layer. The Rest Client provides an interface for receiving and sending information to the remote database as requested by the other layers. It is responsible for sending data about user visits, saved places, updates in progress and personal information. It also provides functions for receiving data from the Server concerning Points of Interest (POI) information and images. It also allows for synchronizing and queuing the requests. While the rest client is responsible for the interactions with the server, the Data Handler is managing the communication of the local content. Information received are parsed and stored in the local DB. The handler responds to events from the views and background service and handles the business logic for the other components. It forms and serves the available information based on the state of the application.

The views are basic user-interface components facilitating the possible interactions with the users. The Map View is a fragment containing a 2D map developed with the Google Maps API. It displays the user's location, as obtained by the background service, and the POIs as markers on the map. The AR view is based on the Wikitude JavaScript API and is where the AR experiences take place. It is a Web view with a transparent background overlaid on top of a camera surface. It displays the 3D reconstructions while it receives location updates from the background service and orientation updates from the underlying sensor implementation. It also contains a navigation view, where the POIs are displayed as labels on the real world. Interactivity is handled in JavaScript and it is independent from the native code. The View pagers are framework specific UI elements that display lists of the POIs, details for each POI, user leader-boards and user profiles. Finally, the Notification View is used when the application is in the background and aims to provide control over the location service. It is a permanent notification on the system tray where the user can change all preferences of the location strategy and start, stop or pause the service at will.

The aim of the standalone background service is to allow users roam freely in the city while receiving notifications about nearby POIs. It is responsible for supplying the locations obtained by the GPS to the Map View and AR Views. The location Provider obtains the locations and offers the option to swap between the Google Play Services API and the Android Location API; e.g. two location strategies. In order to offer control over battery life and data-usage, the users can customize its frequency settings from the preferences. The views requesting location updates are registered as Listeners to the Location Service and receive locations containing latitude, longitude, altitude, accuracy information etc. The Location Event Controller serves the location events to the registered views. The user's location is continuously compared to that of the available POIs and if the corresponding distance is in an acceptable range, the user can interact with the POI. The events sent, include entering and leaving the active area of a POI. If the application is in the background, a notification is issued leading to the AR Views and Map Views.

The Model layer consists of standard storing units and handlers to enable parsing JSON files obtained from the server and interfaces to interact with the local DB. It stores the historical information concerning the current local, user specific information and additional variables needed to ensure the optimal flow of the application. The local assets, including the 3D models and the html, JavaScript files required by the Wikitude API, are stored in this layer and provided to the Handling layer as requested. The SQLite Helper is the component responsible for updating the local storage and offers an interface to the Data Handler containing all available interactions.

5 MAR USER INTERFACE

The main technical challenge was to visualize, on-site, the 3D reconstructions of monuments displayed on a standard mobile phone, merged with the real-world offering a location-aware experience. In this section, we present the final user interface of the application and the flow of the experience. Upon the activation of the application the user is welcomed in a splash screen and is requested to create an account or login with an existing one. After the login process, the application checks the location and requests the POIs and the historical information from the server while it transfers to the main screen. The map activity forms the main screen of our application and facilitates the core of the functionality as shown in Figure 4. POIs are displayed on the map in their corresponding geo-locations. By clicking on a marker, the user can see the info window of the POI containing information, a thumbnail and the distance between POIs.

Figure 3: 3D reconstruction of the Glass mosque featuring the now demolished minaret, as seen by MAR users.

Figure 4: Map view displaying the POIs.

By interacting with a bar at the bottom of the screen, the user navigates the app. These include user profile and preferences, leader-boards and the library while a round button placed in the middle is used to swap between map and camera navigation.

The Camera View displays the real-world content as 2D labels, which contain basic information about the POIs and displays them as dots on the radar to assist in navigation. By clicking on a label, a bottom drawer appears which holds additional information and allows for more interactions. Users can save the POI for later reference, access the reconstruction if available, or return to the map. The main concept of the experience is to reveal the available information under controllable conditions, to facilitate a diverse range of textual, image and 3D interactions.

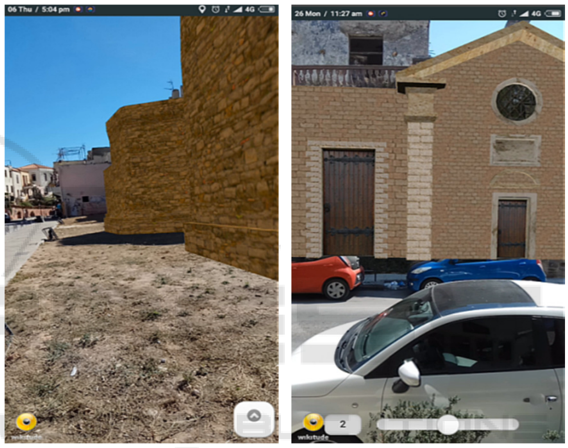

Figure 5: Reconstructions of the demolished towers of the Byzantine Wall and the restoration of the Rocco temple.

When in the initial state, the user is shown the available 3D reconstructions on the map. After visiting the monuments and viewing them in AR, the rest of the POIs locations are unlocked and displayed on the map indicated as question marks. The goal is to visit them and classify them to the historical periods based on their architectural characteristics and on clues obtained in the library page and from the already visited monuments. The exploration of the POIs can be conducted freely by employing the background service of the app. The users enable or disable this functionality. The aim of this approach is to urge the visitor to observe the monuments, consult the information available and even interact with each other and locals to make each decision. The more areas they visit and unlock, the more points they earn for themselves. The overall progress in the city can be viewed in the Leader-boards page, accessible from the map view.

The 3D reconstructions are the main feature we aimed to provide as shown in Figures 3, 5. By situating information in the context of their real surroundings, we aim to elevate the communication of cultural and historical information from static forms to visual standards. The 3D reconstructions are accessed from the navigation views. When the user is in close proximity to the monuments, the location Event Handler informs the views to update the content and enable the AR experiences. In this screen, a reconstructed 3D model of the monument is overlaid on the camera and the GPS and inertial sensors are exploited to display the monument on its real world location. The users can freely move around the real site to view the monuments from all available angles. They can click on the model to get information or access the slider, available at the bottom right, to change between the available 3D models. The user can shift between visualizing either the whole model or the reconstructed parts.

The Library page is where a collection of the historical information is displayed (Figure 6). It consists of a view pager containing the historical periods in chronological order. Each page includes a historical briefing and an image showing the active area for that period as well as a list containing the monuments that have been correctly classified. The locked monuments are contained in a separate list. The users can see the monument-specific information by selecting the items on the list. The user can also acquire historical information, including text and images, mark and save monuments or get directions to specific locations.

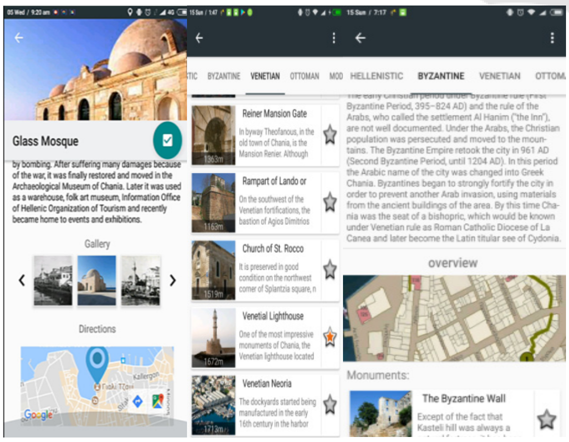

Figure 6: Pager View of Library, Monument details page.

6 EVALUATION

The MAR functionality as well as generic user interface of the application was constantly evaluated since the start of the technical development. Users communicated comments concerning the AR camera view during navigation stating that the use of the camera instead of the map limited their movements and perception of their surroundings and generally refrained from using it except to locate specific sites and to classify the monuments. During the classification process, the AR camera proved useful as it helped locate specified monuments. Moreover, when the AR camera was on in conjunction with the GPS, high battery consumption was an issue. Following such comments, the AR camera was defined as a standalone activity instead of as map replacement.

In relation to users' general impression using AR experiences, user feedback was quite promising. Most users had never been acquainted with a similar application and were very excited to see the reconstructions superimposed on the real-world monument. Although the registration problem was commented by most users, the geo-location approach was intuitive. The instant tracking method was overall challenging for an unaccustomed audience, but after an initial explanation and guidance, users got used to it and proceeded to experiment with placing the models in the annotated area so that they are accurately overlaid on the actual real-world building, as viewed on the mobile phone.

7 CONCLUSIONS

We presented the design of a mobile Augmented Reality application, geo-located and gamified, aimed for consumer-grade mobile phones increasing the synergy between visitors and cultural heritage sites. In addition to exploring application screens and web content, we offer a novel AR approach for visualizing historical information on-site, outdoors. By offering 3D reconstructions of cultural sites through AR, we enhance digital guide experience while the user is visiting sites of cultural heritage and bridge the gap between digital content and the real world. Our design was focused on providing an expandable platform that could envelop additional sites enabling future experts to display their digitized collections using cutting edge AR technologies.

Although outdoors Mobile Augmented Reality is still hampered by technical challenges concerning localization and registration, it offers novel experiences to a wide audience. The availability and technological advances of modern smart phones will allow, without a doubt, seamless and fascinating AR experiences enhancing the understanding of historical sites and datasets.

The field of Augmented Reality is a quickly evolving. Tracking and registration in AR are far from solved. Employing a low-level AR SDK, such as the AR-toolkit, would provide access to low level functionality. In its current state, the application does not support interaction between the users, apart from the overall rankings. Extending the platform to include comments, likes, shares etc. and adding an additional communication layer would increase interest in cultural heritage. Gamification combined with scavenging and treasure hunts, location-aware storytelling etc. would add to an even more immersing experience and increase visitor involvement and engagement.

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