Using augmented reality for architecture artifacts visualizations

Zarema S. Seidametova[1], Zinnur S. Abduramanov[1] and Girey S. Seydametov[1]

[1]Crimean Engineering and Pedagogical University, 8 Uchebnyi per., Simferopol, 95015, Crimea

Abstract
Nowadays one of the most popular trends in software development is Augmented Reality (AR). AR applications offer an interactive user experience and engagement through a real-world environment. AR application areas include archaeology, architecture, business, entertainment, medicine, education and etc. In the paper we compared the main SDKs for the development of a marker-based AR apps and 3D modeling freeware computer programs used for developing 3D-objects. We presented a concept, design and development of AR application "Art-Heritage" with historical monuments and buildings of Crimean Tatars architecture (XIII-XX centuries). It uses a smartphone or tablet to alter the existing picture, via an app. Using "Art-Heritage" users stand in front of an area where the monuments used to be and hold up mobile device in order to see an altered version of reality.

Keywords
Augmented Reality, smartphones, mobile-AR, architecture artifact, ARToolkit, Vuforia

1. Introduction

In recent years, Augmented Reality (AR) has been named as one of the top 10 new technology trends. AR technology has primarily been used for gaming but nowadays it has also found widespread use in education, training, medicine, architecture, archeology, entertainment, marketing and etc. According to the International Data Corporation (IDC) [1] worldwide spending on AR and virtual reality (VR) is growing from just over $12.0 billion this year to $72.8 billion in 2024.

AR as technology allows researchers, educators and visual artists to investigate a variety of AR apps possibilities using mobile AR in many areas – from education [2, 3, 4, 5, 6] to cultural heritage [7, 8, 9, 10, 11].

In the paper [12] authors provided an overview of Augmented Paper Systems use in education. Studies related to the effect of augmented reality on learning efficiency presented in papers [13, 14], in which also discussed questions on how to combine the capabilities of augmented

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z.seydametova@gmail.com (Z. S. Seidametova); abduramanov.z.s@gmail.com (Z. S. Abduramanov); s.girey.s@gmail.com (G. S. Seydametov)
http://cepulib.ru/index.php/ru/resursy/personalii/47-s-personalii/169-sejdametova-zarema-sejdalievna (Z. S. Seidametova); https://kipu-rc.ru/sotrudniki/103-abduramanov-zinnur-shevketovich.html (Z. S. Abduramanov); https://kipu-rc.ru/fakultet-ekonomiki/kafedra-prikladnoj-informatiki.html?id=107 (G. S. Seydametov)
0000-0001-7643-6386 (Z. S. Seidametova); 0000-0002-2818-4759 (Z. S. Abduramanov); 0000-0002-1004-4141 (G. S. Seydametov)

reality and learning activities. The educational potential of augmented reality technology and benefits which AR can bring to teaching and learning discussed in the papers [15, 16, 17, 18, 19].

An experience of the successful use of AR mobile applications in learning and teaching process described in [20, 21]. There is large number of studies, which identified the future trends, affordances and challenges of AR systems in education. The papers [22, 23, 24, 25, 26] provided research on the problems that can help to improve the experience of using AR systems in education and authors of papers suggested the new AR educational tools [27, 28, 29].

Garzón et al. [30] highlighted five directions for future research: (1) design of AR systems that consider special needs of particular users; (2) integration of AR systems into unexplored fields of education; (3) inclusion of AR systems into learning processes of unexplored target groups; (4) integration of AR systems into business and industry; (5) design of pedagogically efficient AR systems.

Radu [31] provided a comprehensive understanding of how the medium of augmented reality differs from other educational mediums. Research of Garzón et al. [32] identifies positive and negative effects that AR experiences can bring to learners.

The authors of the papers [33, 34, 35, 36, 37, 38] proposed functional mobile augmented reality applications for different domains not only for education. In papers [39, 40] researchers discussed the effects of marketing, usability, design on augmented reality technologies and ways of the development of AR apps. Comparative analysis of augmented reality frameworks that are used to develop educational and industrial applications presented in [41, 42, 43, 44].

Mekni and Lemieux [45] introduced in the technologies that enable an augmented reality experience, clarifies the boundaries that exist between AR and Virtual Reality (VR); classified the AR-applications into distinct categories: medical, military, manufacturing, entertainment, visualization, robotics, education, marketing, geospatial, navigation and path planning, tourism, urban planning and civil engineering.

The paper [46] provided an overview of 3D interaction techniques in mobile AR, authors described three main interaction technique categories that applicable in mobile AR: touch-based interaction, mid-air gestures-based interaction, and device-based interaction techniques.

The paper [47] investigated the AR technology with a approach based on patent research. Authors searched the United States Patent and Trademark Office (USPTO) for AR-related granted patents in the period 1993–2018. The study found that AR technological development has especially increased in the last decade.

The rest of the paper is organized and structured as follows. Section two, presents an explanation of concepts and technologies of the different new trends such as Virtual, Augmented Reality and Mixed Reality. Section three, explores 3D modeling of the “Art-Heritage” application objects. Section four, presents the “Art-Heritage” application server configuration. Conclusion and future work is presented in section five.

2. Concepts and technologies of the Extended Reality

Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) technologies can be described with an umbrella term Extended Reality (XR). XR covers all of the various technologies that giving additional information about the real world or creating virtual worlds:

- AR adds digital objects to a live view by using the camera on a smartphone (for example, Snapchat lenses, Google's "Just a line", Pokemon Go, etc.). AR contains following basic features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects.
- VR devices such as HTC Vive Headset, Oculus Rift, Oculus Quest 2, Sony PlayStation VR, HP Reverb G2 or Google Cardboard move users into a number of real-world and imagined environments. VR is digital, computer-generated and 3D environment that allows the user to step inside the virtual world. There are main types of VR simulations used today: non-immersive, semi-immersive, and fully-immersive simulations.
- MR combines elements of both AR and VR, real-world and digital objects interact. MR-technology is starting to take off with Microsoft's HoloLens. Physical and digital elements exist and interact in real time in mixed reality (MR) applications. MR merges real and virtual worlds, and allow to produce new environments. There are a lot of MR-applications for design, entertainment, training, learning, architecture, healthcare and etc. MR is the area between the real and the virtual worlds and can be represent as augmented reality (the virtual augments the real) and as augmented virtuality (the real augments the virtual).

AR software development kit (SDK) allows developers to build objects that appear to blend into the real world. The AR SDKs offer functions such as 3D object tracking, image recognition, visual search, multi-tracking, and more, which allow developers to produce digital images. There many different SDKs for creating custom AR experiences. The comparison of the most popular AR SDKs based on license type, marker, 3D object tracking, visual search and content API is presented in the table 1.

For development of the "Art-Heritage" application we chose the Unity platform and Vuforia SDK because of the accessibility, availability of the necessary functionality, the possibility of connecting additional sets of development tools and the availability of peripheral (additional) services. The main benefits are that Vuforia enables to maintain tracking even when the target is out of view and Vuforis has cloud database for storing image targets.

The "Art-Heritage" application research objective created in order to promote Crimean tatars historical monuments in the Crimea [48, 49] that are currently destroyed. The "Art-Heritage" is AR application. We recreated four models: Khan Baths (Hammam), Devlet Palace (Sarai), Mengli Geray Mosque, Yesil-Jami Mosque in the "Art-Heritage" app. The interface of the "Art-Heritage" application is presented in the figure 1.

3. 3D modeling of the "Art-Heritage" application objects

3D modeling is used in various industries like movie, animation and gaming, interior design and architecture. They are also used in the medical industry to create interactive representations of anatomy objects or in military training to decorate the environment of the 3D immersive worlds. A wide range of the 3D applications are also used in constructing digital representation of models, assembling elements and observing their functionality.

The list of some 3D modeling freeware computer programs used for developing a mathematical representation of 3D-objects and supported 3D rendering is following:

Table 1
Comparison of the most popular Augmented Reality SDK (based on [41])

AR SDK	Type	Marker	3D object tracking	Visual Search	Content API
EasyAR	Free + Commercial SDK	+	+		
HERE Mobile SDK	Free + Commercial SDK	+			HERE Maps, LiveSight API
Kudan AR Engine	Free + Commercial SDK	+	+	unlimited local visual search (no network connection required)	
Wikitude	Free + Commercial SDK	advanced	+	Cloud Recognition and Offline (on device)	with Wikitude Studio and Cloud Recognition
Vuforia	Free + Commercial SDK	Advanced, VUmark	Only on box and cylinder and small size 3D objects	+	With Vuforia Cloud
DroidAR	Free	+	+	can be added via openCV	OpenGL, jMonkey engine
Xloudia	Commercial SDK only	Markerless	+	+	REST
Catchoom	Free + Commercial SDK	Markerless		Supports both cloud for very large collections and on-device search of hundreds of images	
ARLab	Free + Commercial SDK	QR codes		Support for thousands of images in pools of 50-60 images	

- **3D Slash** (https://3dslash.net) offers complex geometrical shapes to handle (cylinder, sphere or cone), the bucket (to fill in with cuboid an identified volume). 3D Slash app is available for Windows, MacOS and Linux. A special version is also available for Raspberry Pi.
- **Anim8or** (https://anim8or.com/) is an OpenGL-based 3D modeling and animation program. The interface is separated into four sections (with its own tools): object editor, figure editor, sequence editor, scene editor.
- **Art of Illusion** (http://artofillusion.org/) provides tools for 3D modeling, texture mapping, and 3D rendering images and animations. It can also export models for 3D printing in the STL file format.
- **AutoQ3D Community** (https://www.autoq3d.com/) is a cross-platform CAD software, suited for beginners who want to make rapid 3D modeling, texturing, sketching and drawing in 3D.

Figure 1: The interface of the “Art-Heritage” application.

- **Blender** (https://www.blender.org/) is an open-source 3D graphics software toolset used for creating animations, visual effects, paintings, 3D printed models, interactive 3D applications, virtual reality, and computer games.
- **BRL-CAD** (https://brlcad.org/) is a modeling computer-aided design system and includes an interactive geometry editor. It can be used for a variety of engineering and graphics applications.
- **Clara.io** (https://clara.io/) is a full-featured cloud-based 3D modeling, animation and rendering software tool that runs in browser.
- **Daz Studio** (https://www.daz3d.com/daz_studio/) is a 3D scene creation and rendering application used to produce images, animations.
- **DesignSpark Mechanical** (https://www.rs-online.com/designspark/mechanical-software) is 3D computer-aided design modeling software for modeling in a 3D environment and creating files for use with 3D printers.
- **FreeCAD** (https://www.freecadweb.org/) is an open-source general-purpose parametric 3D computer-aided design modeler and a building information modeling software.
- **Makers Empire 3D** (https://www.makersempire.com/) is designed to introduce 4-13 year old students to “design thinking” and engage them in authentic, real-world problem solving via 3D design and 3D printing.
- **Open CASCADE** (https://www.opencascade.com/open-cascade-technology/) is an open-source software development platform for 3D CAD, CAM, CAE. It is a software devel-

opment kit (SDK) intended for the development of applications dealing with 3D CAD data.

- **OpenSCAD** (http://www.openscad.org/) is an application for creating solid 3D CAD objects. An OpenSCAD script specifies geometric primitives (such as spheres, boxes, cylinders, etc.) and defines how they are modified and combined to render a 3D model.
- **Sculptris** (https://zbrushcore.com/mini/) is a virtual sculpting software program with a primary focus on the concept of modeling clay. 3D meshes (.obj) can be imported into the program for further detailing, generating normal and displacement maps. Application functions are sculpting, dynamic tessellation, UV texture painting, cavity painting.
- **Seamless3d** (http://www.seamless3d.com/) is an open-source free 3D modeling software and available under the MIT license.
- **SelfCAD** (http://selfcad.com/) is an online computer-aided design browser-based and cloud-based software for 3D modeling and 3D printing. It is an online software as a Service and allows users to model, sculpt and slice for 3D design and 3D printing.
- **SketchUp** (https://www.sketchup.com/) is a 3D modeling software for applications such as architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design. It is available as a web-based application. It has an open library 3D Warehouse in which users may upload and download 3D models to share.
- **Sweet Home 3D** (http://www.sweethome3d.com/) is an architectural design software application for creating a 2D plan of a house, with a 3D preview, and decorating exterior and interior view including ability to place furniture and home appliance. In Sweet Home 3D, furniture can be imported and arranged to create a virtual environment.

All 3D models of the "Art-Heritage" app were created using SketchUp. The main advantage of SketchUp is the ability of the program to suggest the most convenient next step and method of action. In SketchUp there are many useful tools like geometric modeling and drawing, which includes many functions, construction, also represented by various possibilities. Figure 2 presents the 3D model of the Khan Baths (Hammam) of the 15th century that used to be located in the neighborhood of Zincirli Madrasa (Bakhchysarai, Crimea).

Convention of the objects modeling for the "Art-Heritage" Platform:
(strict adherence to all clauses of the convention is assumed)

1. 3D modeling software: preferably **SketchUp**, other options can be discussed.
2. Texture resolution: **512×512 px**.
3. Number of polygons: up to about **50,000**.
4. Do not allow unnecessary meshes in the model. **Only the exterior view of the object** is required.
5. **If the object exceeds the permissible norm**, then it is required to reduce the detail of ornaments and other small elements:
    - if the ornament is on a plane and it is possible to replace a complex three-dimensional pattern with a texture, then it is recommended to replace it with a more geometrically simple element (cone, spheres, boxes, cylinders, etc.) with further texture overlay on this object,

Figure 2: “Art-Heritage” 3D model of the Khan Baths (Hammam) of the 15th century that used to be located in the neighborhood of Zincirli Madrasa (Bakhchysarai, Crimea).

- if possible, you can resort to reducing the polygonality of some decorative elements, but so that the appearance does not suffer (as much as possible).

(**important notice**: *to optimize from less significant details to more significant ones* - i.e. it is better to neglect the quality of some insignificant, inconspicuous element than the one that first catches the user’s eye).

For visualization of 3d models in the “Art-Heritage” app we use QR-codes. Figure 3 presents the stand with QR-codes, the Khan Baths (Hammam) 3D model’s QR-code and the image of the Mengli-Geray Mosque

4. The “Art-Heritage” application server

Server part of the “Art-Heritage” application.

It is used Virtual Dedicated Server (VDS) for working with the database storing 3D models data. To provide access to 3D models data through the API we use a RESTful web service that is well suited for creating API for client spread out across the Internet. Client and server exchange

Figure 3: The Stand with QR-codes for “Art-Heritage” 3D models. The Khan Baths (Hammam)3D model’s QR-code; the image of the Mengli-Geray Mosque.

representations of resources by using a standardized interface and protocol. The access to calling API methods have only those routers whose data are stored on the server in the database and located in the same Virtual Local Area Network (VLAN). VLAN is a function in routers and switches that allows to create multiple VLANs on one physical network interface (Ethernet, Wi-Fi interfaces). VLANs are used to create a logical network topology that is independent of the physical topology.

A Virtual Private Network (VPN) tunnel with a pool of addresses is configured on the VDS server. VPN is a secure, encrypted connection between two networks or between a user and a network. When registering a new museum or adding an additional access point to the museum, the router (which is located in the museum) receives its IP address in the pool and binds to the MAC address.

Client part of the “Art-Heritage” application.

The client is provided with a router based on “routerboard’’. When registering an access point, the museum receives a login and password for the CRM control panel, from where it can control the activity of the access point.

The client downloads the firmware (which is assigned to one router) and automatically flashes the router (manual configuration is also possible). Important note: the client's router must have a USB connector that can work with external drives that could store 3D models.

After the tunnel is built on both sides, the server checks for the presence of 3D models that are assigned to a specific router on its drive and performs synchronization (if it is necessary, the models are downloaded from the server to the server's local storage).

When flashing a router, hotspot has a strictly fixed pool of addresses, in particular the IP of the gateway, since the URLs in the application are hardcoded to work with models from the museum's local storage. Sharing a local drive that is connected to the router is implemented using FTP server on the local router.

Figure 4 shows a fragment of the listing of the router_config.rsc file for configuring the hotspot and routing.

```
#--------------------------------------------
# Hotspot Setup
#--------------------------------------------

/ip hotspot profile
add hotspot-address=xxx.xxx.xxx.xxx html-directory="/disk1/hotspot" login-by=http-pap name=arhsprof
/ip hotspot user profile
set [ find default=yes ] idle-timeout=1d keepalive-timeout=1d on-login="/ip firewall address-list add
list=AUTHORIZED address=\$address timeout=24:00:00" on-logout="/ip firewall address-list remove
list=AUTHORIZED address=\$address"
add name=uprof1 shared-users=50
/ip hotspot user add name="<hotspotUser>" password="<hotspotPassword>" profile=uprof1
/ip hotspot add address-pool=hs-dhcp addresses-per-mac=200 disabled=yes interface=bridge
name=ARHotspot profile=arhsprof
/ip dns set allow-remote-requests=yes cache-size=1048KiB max-udp-packet-size=512
servers=8.8.8.8,8.8.4.4
/ip firewall nat add action=masquerade chain=srcnat comment="masquerade hotspot network" src-
address=xxx.xxx.xxx.xxx/xx

# Routing
/interface pptp-client add name=arch connect-to="<host>" user="<Username>"
password="<Password>" disabled=no
/ip firewall nat add chain=srcnat out-interface=arch action=masquerade
/ip firewall mangle add chain=prerouting src-address=xxx.xxx.xxx.xxx-xxx.xxx.xxx.xxx action=mark-
routing new-routing-mark=PPTP
/ip hotspot walled-garden ip add action=accept disabled=no dst-host="crm.****.com"
/ip hotspot walled-garden ip add action=accept disabled=no dst-host="www. ****.com"
/ip route add dst-address=0.0.0.0/0 gateway=arch routing-mark=PPTP
/ip dns static add name=archdns address="<Gateway>"
```

Figure 4: A fragment of the listing of the router_config.rsc file for configuring the hotspot and routing.

The figure 5 presents the detail how operations are carried out and the interaction between objects in the context of a collaboration.

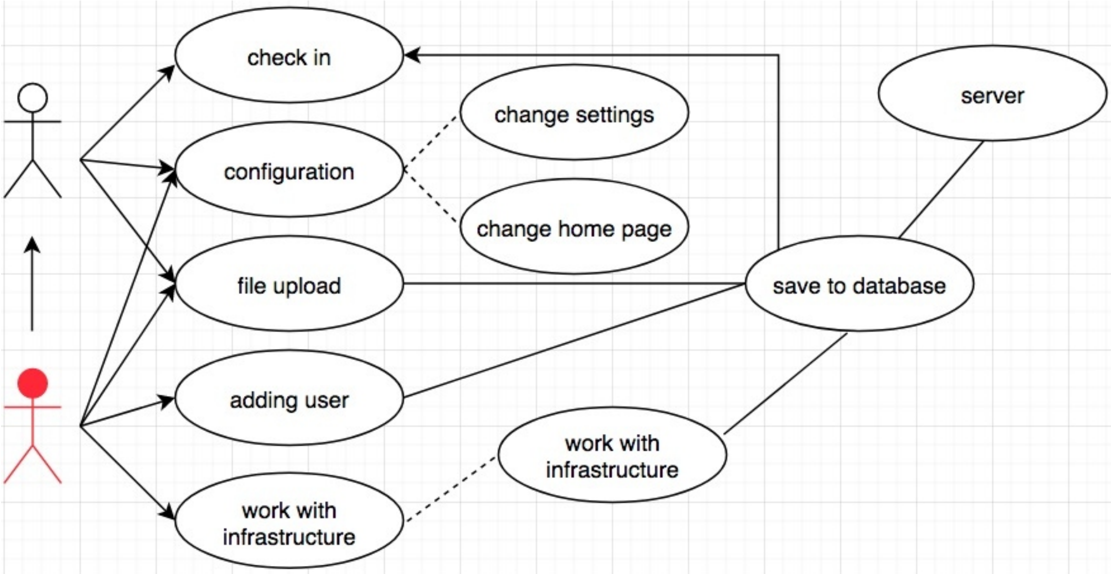

Figure 5: The use case diagram of the “Art-Heritage” application.

The figure 6 presents sequence diagram of the “Art-Heritage” application. The sequence diagram shows objects (user, REST controller, service, data access) interactions arranged in time sequence. The sequence of messages exchanged between the objects needed to carry out the functionality of the of the “Art-Heritage” app scenario. The figure 7 the activity diagram of the “Art-Heritage” application that visually presents a series of actions in a system.

The class diagram of the “Art-Heritage” application is presented in the figure 8.

5. Conclusions

Nowadays the Augmented Reality is one of the most popular trends in software development and one of the most innovative initiatives in education. AR applications offer an interactive user experience and engagement through a real-world environment. The AR technology opens a new horizon for the development of mobile AR applications for archaeology, architecture, business, entertainment, medicine, education. There are a lot of SDKs for the development of a marker-based AR apps that give an opportunity to add a third dimension to displays, bringing objects or scenes to life. There are many computer programs for modeling 3D objects that can be superimposed computer-generated images over real-world views.

The AR application “Art-Heritage’’ developed by us gives the opportunity to bring the monuments of Crimean Tatars cultural heritage to life and learn their stories. The learning is accompanied by 3D visualization and animation of each monument.

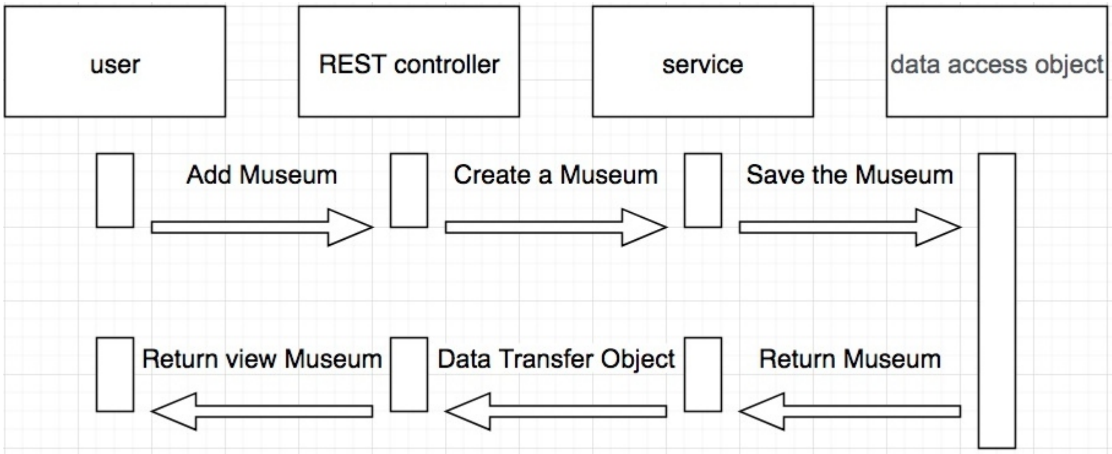

Figure 6: The sequence diagram of the “Art-Heritage” application.

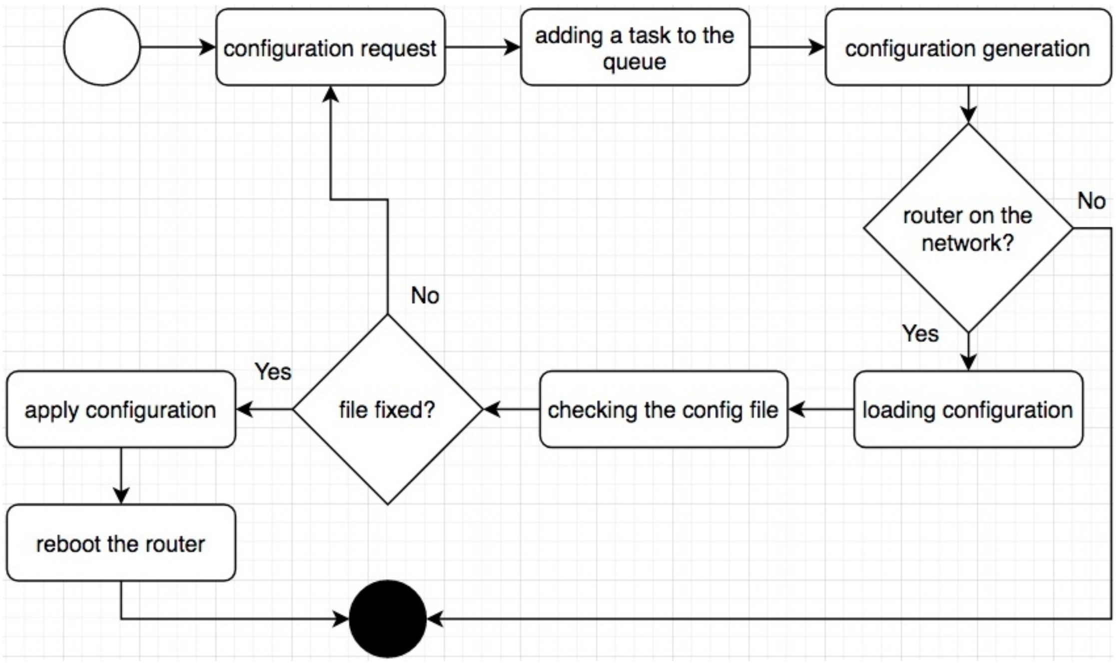

Figure 7: The activity diagram of the “Art-Heritage” application.

In addition, the experience gained from the development of the “Art-Heritage’’ application opens up a new look at the development of mobile AR applications and at the router configuration. In the future we plan to introduce larger numbers of 3D models for architectural historic artifacts, expand the local database of 3D objects, audio explanations to accompany the story of each model.

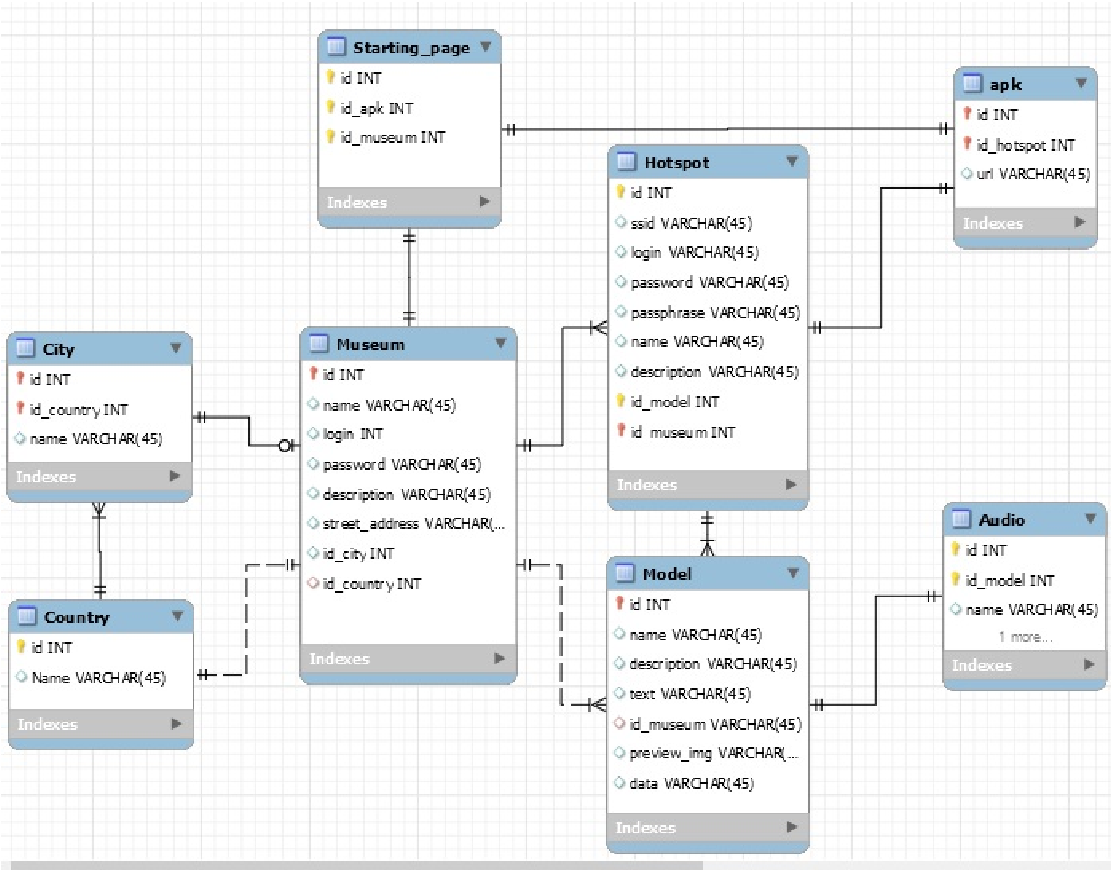

Figure 8: The class diagram of the “Art-Heritage” application.

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