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ARtect, an augmented reality educational prototype for architectural design

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Abstract — ARtect is an Augmented Reality application developed with Unity 3D, which envisions an educational interactive and immersive tool for architects, designers, researchers, and artists. This digital instrument renders the competency to visualize custom-made 3D models and 2D graphics in interior and exterior environments. The user-friendly interface offers an accurate insight before the materialization of any architectural project, enabling evaluation of the design proposal. This practice could be integrated into learning architectural design process, saving resources of printed drawings, and 3D carton models during several stages of spatial conception.

Keywords— 2d graphic, 3d models, application, architecture, augmented reality, education, design

I. INTRODUCTION

This article presents the ARtect prototype, an Augmented Reality (AR) application and online service for mobile devices (smartphones and tablets), intended to facilitate architectural conception, interaction, and visualization of 3D models and 2D graphics in both interior and exterior spaces. The purpose of this tool concerns the educational practices of architecture within the digital realm and particularly with immersive tools. We developed the demonstration of ARtect, as a digital prototype and proof of concept to expedite architectural design and spatial perception in real-time and on-site. ARtect's name derives from Augmented Reality (AR) and the word "architect".

During studies in architecture, we observed that traditional tools for architects such as drawings, and models offer a limited experience regarding the sensory perception of space and the architectural design. Through a questionnaire, we launched to 98 students in architecture, 55% claimed to meet difficulties with architectural scales, and making the transition in between (e.g. From 1:1000 to 1:200). Several cognitive biases affect perception in terms of visual representation and space itself connected to scale factors. To surpass these difficulties, we claimed that architects need immersive tools to obtain immediate contact with real-site factors.

The novelty of this work focuses on training the architect's gaze to experiment with models in real-time on-site environments during the initial stages of design. By placing objects and modifying the scaling factors, the students obtain feedback about the credibility of the design's implementation related to the real scape. We aim to contribute with an immersive augmented reality tool for architectural design.

II. STATE OF THE ART

Augmented Reality evokes a field of full potentials for designers, architects, and artists, as it combines real and virtual information superposed in one single view scene in real-time [1] and 1:1 scale. AR displays generally within the framework of Reality-Virtuality Continuum, suggested by Milgram *et al.* in 1994 [2]. AR allows information, presented visually, that the user would not be able to detect, as it reveals a reality that without smartphones, computer tablets, laptops would remain hidden [1]. This asset of layering real and digital reality, appears particularly useful for teaching architecture, building implementation, and construction learning, through interaction and visual representation. Finally, perception and spatial conception are highly related to the notion of scale, which can be further explored with immersive tools.

A. Scientific Anchoring

Applying to different disciplines such as video games and informatics, there are various strategies suggested about the use of AR by architects. Scientists and educators in architecture assess *learning in location-based AR applications* [3]. Moreover, some products offer a dive into an architect's sketch or augment a completed 3D model in a location. Henceforth, the lack of digital immersive tools for architects and spatial research is apparent [3], combined with a collaborative problem among the different disciplines. It is a challenge to collaborate with developers to design an AR application serving the education of young architects and raise awareness about the use of various digital means.

B. Literature

Many examples of AR applications have been implemented and classified [4] [5] as the history of merging virtual objects with reality is longstanding [5]. *Furht* in the *Handbook of Augmented Reality* [6] presents applications in several domains such as environmental planning, medical training, designing, and mobile AR games. Focusing on the built environment in the field of Architectural Research and Design, in 2011, *Kim et al.* reviewed 44 articles concerning AR and architectural design, concluding in four aspects of AR applications: AR concepts, AR implementation, AR evaluation, and AR industry's adoption [4].

According to *Wang et al.* [7] classification, these four stages consist of the architecture layer framework of AR systems, explicitly presented as:

a) Concept and Theory (AR Concept): consists of algorithms and modelling, conceptual and evaluation framework, and technology adoption.

b) AR Implementation: includes Software and Hardware information and interaction design.

c) AR Evaluation: this layer describes the usability and the effectiveness of the application.

d) AR industry's adoption: applications embraced by the industries of building constructions.

The ARtect project is conceived as a digital prototype for architects and design studio learning processes.

This document is organized based on Wang's analysis.

III. ARTECT CONCEPT

ARtect aims to develop creativity and expression during visits on-site with students of architecture. The user experience includes:

- Creation of an AR scene by the placement of multiple 3D models and 2D graphics in real-time, via a personalized library, on geographical locations (indoors and outdoors).
- Manipulation of virtual objects in three-axes (x,y,z).
- An immersive walkthrough in the 3D AR scene.
- A measurement tool in AR that permits to calculate distances by drawing a line on the scene.
- Snapping Objects.
- 2D and 3D scaling in the AR scene.
- Exporting created AR scene.

A. User Experience

The ARtect interface is a user-friendly, digital environment and no extra knowledge in informatics is required by students in architecture. The interaction comes through the touch screen of a smartphone or a tablet. The user needs a compatible Android/iOS portable device [8], and the ARtect software installed.

There are two possibilities of using the application, one where the user augments standard geometries (e.g. a cube) (Fig.1) and the setting where the user uploads custom-made 3D models and/or 2D graphics to create an augmented reality scene (Fig.4). Analytically, the two modalities of use are:

1) Standalone setting

In the standalone mode, the interface provides the standard geometries, a cube, and a sphere, and offers an empty AR scene ready to host a constructivist learning environment (add, remove, modify objects) for the user (Fig.1).

The participant can modify (move, rotate, scale, copy) the prefabricated standard geometry and use it as an augmented unit of construction. Furthermore, the user can select the measurement tool to calculate distances horizontally and vertically between points (Fig.2).



Fig. 1. ARtect prototype, AR Grid and examples with snapping cubes.

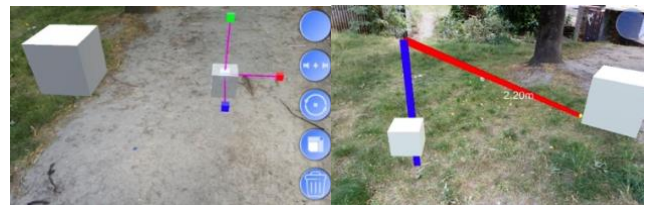


Fig. 2. Scale (right) and Measurement distance (left) tools.

2) Online Platform setting

The Online Platform permits to upload custom-made 3D models and graphics and, then, download AR scenes made by the users. For this, the user needs a laptop with Internet access.

First, each participant creates a personal profile and logs in [9]. Using the personal profile, the participant uploads his/her ideas online and then can create an AR scene anywhere, using the spatial elements, through the application. Students in architecture can transfer virtual objects such as buildings, trees, urban equipment, etc. Participants can use multiple virtual objects on the scene.

The content of the AR scenes belongs to the user.

B. Ease of Use and Interface

We describe the ease of use in 5 steps, as presented in the flow chart of the application and service (Fig.3).

1) Scene Configuration

Once the AR camera of the portable device is activated, the user can start the scene configuration. First, the user points towards the ground to scan and detect a *flat* surface in the physical environment, until the AR Grid appears (Fig.1). When the grid appears, the application is activated. This grid anchors the objects to the ground and permits the application to "know" precisely where to place each virtual object (width and depth).

2) Object Digital Library (ODL)

The interactive interface of the application contains the Object Digital Library. Through the ODL, the user selects an object with the touch screen and drags and drops it in the scene. The ODL is compatible with 3D models with the format .obj and .fbx which many 3D modelling software support, such as Rhino, SketchUp, and 3ds Max, which architects use. Also, the digital library collaborates with images in .png format, such as the images of the trees (Fig.4).

3) Toolbar

The interface gives the possibility to modify the 3D/2D imported virtual objects. This toolbar exists to adjust a virtual object on the digitally augmented environment, and modify the scale and the object's orientation. It includes the following functionalities: Move, rotate, scale, copy, delete an object, a measurement tool, and a hide-interface button (Fig.4).

4) Download Environment

The Object Digital Library is connected to a server that stores the objects on the ARtect Online Platform (cloud). The user can save and export the AR created environment to the personal cloud profile. The user has the possibility to download to a laptop/desktop, the models once created on-site, and which can be further edited in any 3D modeller. This asset gives architects, the possibility to create 3D spatial content directly on the real background at the initial stages of brainstorming and edit it later at the design studio.

5) Upload 3D/2D Virtual Object

Via the ARtect online service, the user can upload custom models and images. The application automatically updates the virtual objects to the app's library, which then appear on the application's interface.

In both cases, standalone and eased by the online platform service, AR scenes of the application can be stored on the personal user profile on the online platform.

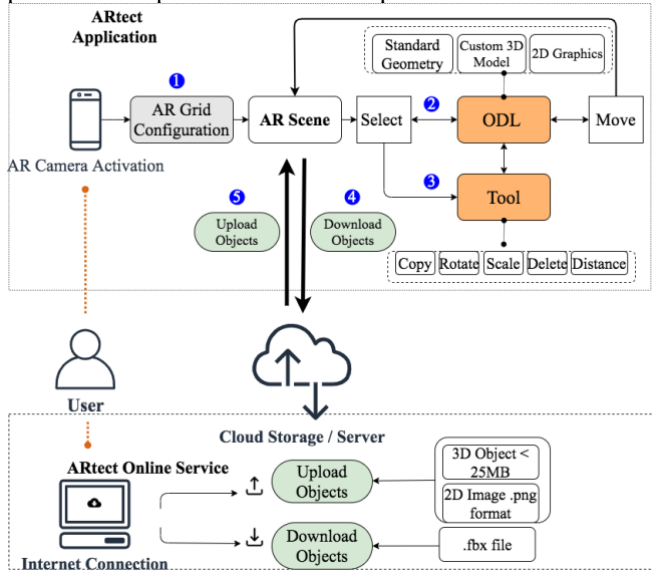


Fig. 3. ARtect prototype Flow Chart, Application and Online Service.



Fig. 4. ARtect interactive interface, personal Object Digital Library (bottom) and toolbar (right).

IV. IMPLEMENTATION

A. Hardware

The application is compatible with both Android and iOS devices that are supported by Google ARCore [8].

B. Software

To accomplish the mission of overlaying various virtual objects onto the real world, the *demo* is composed of an AR application (client) and a web service platform (server). Both the mobile application (client), and the online platform (server) are developed using *Clojure* [10], a dynamic and wide-purposed programming language.

1) Application

The ARtect application is developed with the software Unity 3D and Clojure. Manipulation of 3D objects in an AR digital environment is challenging since the 3D environment of the real environment is superposed with the 2D environment of the screen. Several limitations appeared such as obtaining a 6Dof experience (Degrees of Freedom)[11], into the AR scene. As several pieces of research [12] have shown, the placement of a virtual object onto the augmented scene and the free movement of this object within the 3 axes (x, y, and z-axis) with precision, presents a fundamental difficulty. Also, lighting and orientation limitations were among the topics that the development of the AR prototype had to surpass to create an interactive instrument for architects. Ultimately, the selection of each object with the touch screen setting had to be improved, since it can appear less accurate than the mouse input. The specificity of the functionality of this application that focuses on architectural design and visualization led to a tailor-made domain-specific language (DSL).

The steps taken to overcome particular technical issues are the following and therefore the adjustments of the software:

a) The ARCore grid provided by Google met with some limitations, which resulted in overlapping grids. We overcome this constraint by estimating different heights of the ground. Extract from the code regarding the solution.

```
(defn combine-grids
  "Combine vertical overlapping grids"
  [detected-grids]
  (mapcat #(when (vertical? %)
             (if-let [overlap (overlaps? % detected-grids)]
                 (combine-grids % overlap) %)) detected-grids))
```

b) In order to overcome the difficulty in movement in the z-axis, we introduced a vertical virtual plane that is created at each imported on-scene virtual object. The user uses two fingers selection mode in order to move the virtual object vertically. Extract from the code regarding the solution.

```
(with-cmpt vertical-plane [tr Transform]
  (set! (-position tr) (.. object transform position))
  (.Rotate tr (v3 90 0 0))
  (set! (-parent tr) (.-transform plane))
  (cmpt+ plane AlwaysFaceCamera))
```

2) Online Platform Cloud

The online platform allows users to upload 3D models as .fbx or .obj files with a maximum size of 25MB. Internally, the server automatically converts the uploaded models to Unity 3D prefabs, to facilitate architects who are not Unity 3D users. The features of the platform are:

a) The objects' dimensions are converted to meters.

b) The pivot point of each object (0, 0, 0) is recalculated to be at the basis of the object, to allow correct rotation, and placement on the scene accurately.

c) Conversion of any material/textures that are not compatible with mobile devices.

The converted objects are automatically saved to the personal cloud profile and become available for use via the application.

V. EVALUATION

We evaluated the functionality of the application with experimentations in the city of Paris in France at the beginning of June 2020. We used 3D models that we created, such as wooden decks, stairs, bridges, and also 3D models downloaded from the 3D Warehouse SketchUp [13] with free licences such as statues, ionic columns, and urban equipment. Lastly, we used 2D images of trees in 3 different seasons (summer, spring, and autumn)(Fig.4). These elements were satisfactory to create AR scenes in different emplacements, to modify, and play with these spatial forms on-site.

Our experimentations included placing augmented objects on non-stable surfaces, such as the water of the canal to verify if the ARCore grid still worked (Fig.5).

Furthermore, we evaluated the distance of the calibration of the AR grid, since it worked from the height of a small bridge when we scanned the water (Fig.6). The concept of this experiment was to suggest floating decks and nature in the ecosystem of the canal St Martin (Fig.7).

Lastly, we managed to create an AR scene at the Eiffel Tower with simple spatial elements and walk through the digital environment, obtaining observations and remarks about the natural and the digital environment (Fig.8). The different angles of perspective in AR in real-time permitted to understand better the 3D space. The accuracy and stability of the augmented objects on the scene gave us a 360° field of creation (Fig.8,9,10). We note that in this stage of experimentation, we evaluated only the functionality of the application and not the 3D models presented or the scale of their implementation in the environment.

We, partially, evaluated the application, since we did not have the opportunity to test it with students in architecture, we obtained some feedback, which was positive, from four students in visual arts and cinema that witnessed the experiment. Particularly, they mentioned that it was interesting to create a virtual scene directly on-site and then being able to walk through it, as they characterized the application highly immersive. Besides, the participants mentioned the potential of digital scenography since there is the capacity to place many different objects and interact with them. However, further tests are needed to be able to measure the usability and effectiveness of this instrument.



Fig. 5. ARtect scene evaluation test non-stable surfaces, e.g. river, Canal Saint-Martin, Paris, photo: June 2020.



Fig. 6. ARtect scene evaluation test height and ground tracking from bridge, Canal Saint-Martin, Paris, photo: June 2020.



Fig. 7. Augmented scene result evaluation test height and ground tracking from bridge, Canal Saint-Martin, Paris, photo: June 2020.



Fig. 8. AR scene, Right view of Venus of Milos [16].



Fig. 9. AR scene, Back view of Venus of Milos.



Fig. 10. AR scene Left view of Venus of Milos, Placement of 3D objects and the possibility to walk through the scene, Eiffel Tower.

VI. FUTURE WORK

The adoption of AR applications by the industry is in progress, also many academic types of research and tools have been developed around this subject. Our future work is to develop the methodologies that can integrate tools as ARtect in the official educational curriculum of architects and implement the use of 3D simulation of immersive navigation in a 1:1 scale during the academic architectural projects. To augment with precision virtual objects in real environments, with the use of technological advancements as cameras, sensors, GPS, etc. presents a field of exploration for designers and architects. Moreover, functionalities as changing material and textures, different lighting simulations, and further shaders represent a field for further additions to the application. The application is conceived in order to fusion later with virtual reality possibilities. In conclusion, we wait for the ARCore Depth release that it is announced for this year and permits the 3D objects to better be placed in the

AR scene [14], and improves the 3D navigation inside the digital ecosystem.

VII. CONCLUSION

The findings of this research project are expanded in the proposition of architectural education tools and methods that aim to increase students' attention and perception of the surroundings regarding the notion of scale. This project builds on a learning process in architecture that combines novel interactive technological mediums with architectural design. This approach can cultivate ecological sensibility in architectural education since the student develops an immediate relation between the physical environment and the architectural geometry. The placement of geometric forms in the natural and urban environment increases spatial perception and even learning capacity. ARtect prototype considers the implementation of architectural ideas as a meaningful process to inspire architectural learning by overlaying virtual objects of creation into the real world.

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