ReforestAR: An Augmented Reality Mobile Application for Reforest Purposes

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Abstract: Forest areas are essential to life on planet Earth and, without them, human society would not be able to sustain itself. Yet, they are under constant threat of reduction and damage, and many of them have been lost worldwide. Besides preventing their disforestation in the first place, awareness for maintaining, replanting, and restoring these areas should be raised to live in a greener and healthier environment. Information in modern times is mostly passed on through technology and, with the rise of Augmented Reality (AR), coupling both smartphones (devices that most people use in current times) and nature seems like an opportunity to raise consciousness to the cause. In this paper, we present an application to relate both Augmented Reality and reforestation, to raise awareness of environmental damages by allowing users to virtually place 3D models of trees on a real surface, using their own mobile phones, helping to plan and to visualize the replanting process over previously destroyed areas.

1 INTRODUCTION

Augmented Reality (AR) technology can be perceived as an "enhanced" version of reality or, in other terms, a mixture of a real-world environment with virtual components such as interfaces and objects overlaid on it. One of the technology trends that have been growing more accessible every year, AR is highly responsible for the successful user experiences of the most downloaded applications in the current market, such as online shopping catalogue applications. Some of AR's main uses and functionalities are facial recognition, geolocation, object recognition, and phone tracking.

Nowadays, AR continues to grow significantly and new applications have been and are being developed.

While most AR apps are focused on the entertainment or shopping industry; the mobile application market can also be used for education, entertainment, and others. AR is being increasingly selected to be used to generate awareness in diverse areas, for example, about past landscapes and endangered animals.

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1.1 Context and Motivation

Deforestation is the process of removal of an area that contains vegetation such as trees, shrubberies, and plants. Normally these are natural areas reconditioned for human activities such as agriculture, cattle raising, and the creation of urban cities. According to the magazine World Wildlife Fund[1] (WWF) (WWF - Endangered Species Conservation | World Wildlife Fund, 2021), 31% of the land is covered by forests, and year by year the human footprint in the green areas grows. The main activity that contributes to deforestation is wildfires, being estimated that 94% of it is caused by humans (e.g., lighting bonfires and discarding cigarette butts). The other 6% are caused by natural disasters such as earthquakes, thunder, and hot temperatures during summer. This demonstrates that, if human lapses are reduced, wildfires will too (Deforestation and Forest Degradation | Threats | WWF, 2019).

After a forest cover area is damaged or burnt by a wildfire, a process of reforestation can be initiated to

[1] *World Wildlife Fund* is a sixty-year-old conservation organization that works helping local communities conserve the natural resources in nearly 100 countries.

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recover from damages. A reforestation process can be defined as naturally or artificially, by replenishing an area that has been deforested with trees and plants (Reforestation, 2021), and it happens when there is a public or private interest in recovering that area due to its ecological, social, or production value.

1.2 Objective

In this study, an application is proposed to join both AR and reforestation to raise awareness of environmental damages. By immersing users into a real-time reforestation experience, the objective is to allow users to virtually place 3D models of trees onto real-world surfaces, by use of smartphones, in both iOS and Android platforms.

The application, named "ReforestAR", lets users place virtual trees on detected surfaces, and with this, simulate a reforestation planning experience. This behaviour was achieved by the usage of an algorithm that acknowledges the minimum distance between trees. The application also enables users to personalize the experience with specific options such as scale modification, the quantity of placed trees, and the type of tree that is being placed. Saving, loading, and sharing reforestation projects are also possible.

2 RELATED WORK

Research of available published apps and an extensive scientific review was accomplished to better comprehend the current state of AR in the market, considering its features, user interface and main functionalities.

2.1 Available Published Apps

The market available apps related to reforestation provide some interesting features related to the topic. For example: Reforest App offers the possibility to control the carbon footprint that humans emit with their day-by-day activities (Reforest - Restore the planet and reverse climate change, 2021), or Replant (REPlant, 2015), whose main goal is to create a plants lover's community in Brazil, by dynamic dissemination of stores, fairs, forums and events related to reforestation.

An example of the integration of AR technology with mobile apps is found in the Reforestation of the Imagination (RIT) (Reforestation of the Imagination, 2011), an AR application developed in Unity[2] using the Vuforia[3] framework. The application recognized tree rings of sculptures in an art exhibition and show a 3D model of the tree.

Journals and entities have started to create their own AR apps, for example, The TIME[4] Immersive mobile application (Introducing TIME Immersive, a New Way to Experience TIME's Journalism, 2019) was developed by an American news portal. Within the application, the user can experience immersive AR experiences (Example: simulation of deforestation in the Amazon Forest). Another example is the official mobile application of the World Wildlife Fund (Introducing WWF Forests, now live in Apple's App Store, 2021) that uses AR technology to show the user species of flora and fauna of native forests, even with real sounds and interaction features.

In the addition to the available apps in the market analysed, it is also important to know what scientific studies have been realized in the field of reforestation with this technology in recent years.

2.2 Scientific Review

A mobile application using AR technology for plant recognition was implemented by students at the Technological Institute of the Philippines. It has information on about twenty-five kinds of herbal plants that can be found in the Philippines. The AR feature allows users to scan an image of a plant through the device's camera, it is recognized and, if it is one of the included plants of the database, the 3D object of the plant is created and shown on the screen. When the figure is tapped, information about the species is presented. The authors evaluated suitability, accuracy, learnability, operability, time behaviour, resource utilization, and recoverability of the application by getting users' feedback. Thirty answers resulted in a medium grade of 4,29 out of 5. The application was considered as "acceptable" according to the parameters that were evaluated (Angeles, 2017).

Another mobile application that uses AR technology for plant tracking and modelling was developed by researchers of the Central China Normal University in Wuhan, China in 2019. The

[2] Unity is a cross-platform game engine with its own IDE.
[3] Vuforia is an open-source SDK for creating AR applications.
[4] TIME refers to the American news magazine.

application's main objective was to help people gain interest in plant learning. The application workflow starts with the user taking picture of all 360 angles of the plant with the device's camera. Then, the Vuforia engine obtains information about the tracking object and generates a similar 3D model, that will be shown on the screen after a user tap. For future work, authors promote the usage of recent technologies to create new interactive, interesting, and imaginative ways of learning (Zhao, 2019).

In 2019, researchers from the University Carlos III of Madrid created a game that uses the Internet of Things (IoT), Ubiquitous Computing (UC), and AR technology to simulate a virtual representation of the process of planting and gardening. It is called "The Magic Flowerpot", and the principal objective of the game is to encourage people to learn about vegetation in their local environment. The authors stated that the game work is divided into three phases: 1) taking pictures of the plants that the users aim to grow in their virtual garden, 2) the user "virtually seeds" the virtual plant with the help of the mobile application on a unique location called, the "Augmented Smart Pot" and awaits for its growing, 3) using the application the plant can be placed to any spot, and the "Augmented Smart Pot" can be reused for more seeds. Eventually, the user will have a virtual garden. The authors expect their work to serve as an example of the usage of the IoT, UC, and AR technologies integrating virtual and real environments for learning purposes (Zarraonandia, 2019).

3 METHODOLOGY

The process of planning and development of both mobile applications – iOS and Android – followed the Scrum[5] agile development methodology, allowing the authors to make a progressive series of incremental upgrades over time when adding, updating, and removing features.

Currently, the Portuguese mobile market is ruled by two operating systems (OS): Android by Google[6] and iOS by Apple[7] (Mobile Operating System Market Share Portugal | StatCounter Global Stats, 2021). Since the main goal is to reach the largest number of people, the application was developed for both OS.

The application interacts with different components to work correctly. Figure 1 displays a detailed overview of how the interaction and communication between the back office and Cloud services of Firebase[8] with both iOS and Android operates.

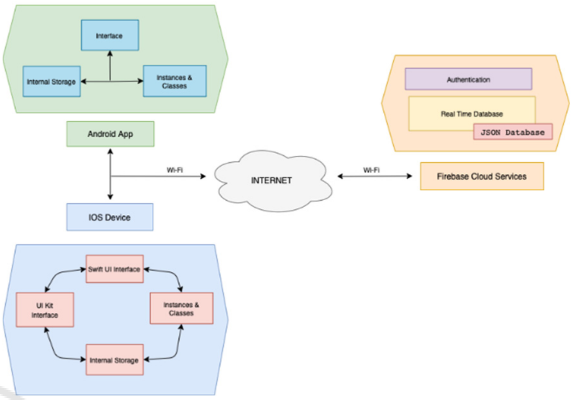

Figure 1: Integration between agents and components.

Data from users of both OS are kept in the cloud, through Google's NoSQL[9] Realtime Database, Firebase. Its structure follows a JSON (JavaScript Object Notation) tree, which is optimized for quick operations that enhance the responsiveness of a real-time experience.

The application has three 3D models available for the user to place in the AR reforestation scene for study purposes, but it has information relative to seventeen species of trees that are native in Portugal.

Even though Vuforia AR SDK is one of the most popular choices for an AR SDK, ARKit[10] and ARCore[11] were chosen instead, due to their native compatibility and for presenting no limitations in their use (no watermark or commercial restrictions).

3.1 ReforestAR Architecture

Figure 2 shows the navigation bar from where the user can switch between five sections: Areas, Projects, ReforestAR, Catalog, and User.

[5] Scrum is one of the most used agile development methodologies.

[6] Google refers to the American multinational technology company.

[7] Apple refers to the American multinational technology company.

[8] Google's Firebase platform to create mobile and web applications.

[9] NoSQL databases store data differently than relational tables, having a variety of types such as document, key-value, wide-column, and graph.

[10] ARKit is Apple's SDK that developers use to create AR mobile applications.

[11] ARCore is Google's SDK that allows developers to create mobile applications with AR features.

The Areas section shows the map with the device's location, where overlaid polygons represent the predefined areas that the system has defined.

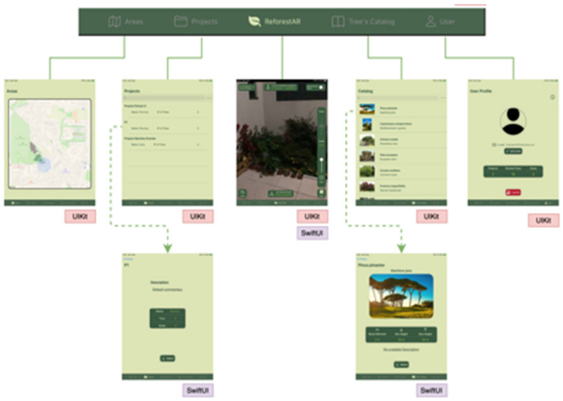

Figure 2: iOS General View Architecture.

The Projects section shows a list of all the reforestation projects associated with the authenticated user. When adding a virtual 3D tree model with AR, its placement is associated with a project. Each project has a specific view that is shown when selected from the list, showing the project's name, description, status, number of trees, associated users, and sharing/deleting functions if the user that is accessing the page is the project owner.

The Trees section shows a list of all the tree species considered in the project's scope. A specific view of each tree is shown when selected, and it shows the tree's Latin name, common name, recommended space between each one when planted, its minimum and maximum height, and a description.

The User section shows the user's name, email, username, statistics about the number of projects of the authenticated user, and the number of planted trees. The login, logout and account registration options are also available here. All registration and login forms have validation functions and error messages when invalid information is inserted.

The ReforestAR section holds the AR view where the main features of the application are available, or in other words, the AR camera.

3.2 ReforestAR Placement Algorithm

When the user taps on an available horizontal surface on the screen, an object is created in that position. The algorithm was created so when the user taps to create objects, it must respect some ground rules as if it was a real reforestation plan. The user can't create an object in a position where there is another virtual object. Every object should have a distance value to prevent this from happening. Now, when the user intends to create more than one object with a single click, the first object will be placed in this position, but it will also be used as the origin position to create new random positions for the new objects that are part of the same tap group. The new positions will go through several comparisons that will verify that they are valid positions to simulate a reforestation environment. If the positions created do not comply, a new position is created and the verifications are made again, having a limit of twenty attempts per position, before failing and communicating to the user that the place where they intend to place the objects does not have enough space.

The three rules that the new random positions must follow are: 1) To be between a "min_distance" and "max_distance" away from the initial position, i.e., the first tap of the user. 2) To be "min_distance" and "max_distance" away from any of the models from the same tap group. 3) To be "min_distance" and "max_distance" away from any models that already existed in the scene before the tap group. The process is depicted in Figure 3.

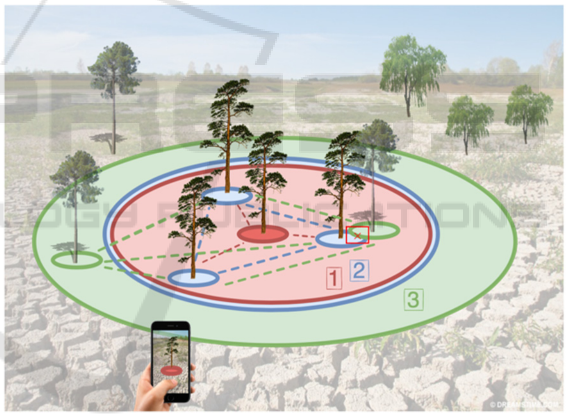

Figure 3: Algorithm implementation, rules visualization.

3.2.1 Algorithm Load Functionality

The process of loading is activated once the user taps in the button, and it will retrieve the information about stored 3D models in the selected project. Then, the placement of these models in the AR environment works differently on each OS. In iOS, the user will select a point in the surface that will serve as the origin position to relate the stored 3D models previous positions. In Android, the initial tap is not necessary since the origin position is calculated automatically, so the objects are placed once the load function is finished.

3.3 Limitations

3D models with a size of more than 200MB were excluded since pilot tests concluded that they were not appropriate for the test device RAM capacity.

Apple's Scene Kit 3D object format "Universal Scene Description" USDZ keeps all the assets of the AR Scenario (including the 3D object) as a folder structure of nested sub-elements from a single "zip file", but when 3D objects were imported to Apple's Scene, some of their features were not correctly applied to the exported 3D object, as perceived in Figure 4. That is why the same models in iOS look different from Android.

Figure 4: Views of both ReforestAR application layout.

Another limitation to consider is that, since the applications were not developed in a unified environment, some elements were implemented differently in each platform according to the available native components of each OS. A greater focus was given to the academic context of the application and functionalities in iOS instead of layout elements.

3.4 iOS Application

The used software to develop the ReforestAR includes Foundation (the base framework of all Swift[12] classes), UIKit and SwiftUI for UI design, MapKit and CoreLocation for map and location services, AR Kit, Reality Kit and Scene Kit for AR features, and the Firebase iOS SDK for integration with database.

ReforestAR Section in iOS was developed with SwiftUI and it is compound by different buttons, labels, sliders, switchers, and pickers with each one of them with a specific function.

Some of the views have either SwiftUI, UIKit components, or both. The way of communicating the changes happening in SwiftUI components to UIKit components is done with the API of the Notification Center [13] and redundancy of variables. SwiftUI components are reactive, so the variables state is kept through the application cycle and it is evident in the user's screen.

Labels that show relevant information, such as the current number of trees that have been placed in the current session and the real-time geographic location of the user's device, were added. A toggle switch activates a functionality that compares the current user's device location to the one stored in the project once the load functionality is triggered. Buttons to remove the last placed tree from the current session, present a view with all available models that may be selected, and display or hide a right bar menu. This right bar menu contains a picker selection for configuring the number of trees to be placed by a single tap (from 1 to 10), a slider that modifies the scale of future placement models, and another button to display or hide a small menu that includes features to delete all the placed trees existing in the current session, select the associated project, and save and load progress from the associated project.

3.5 Android Application

The AR camera interface and functionality in Android operate with minor differences from the iOS version. When the section is selected (or when initially loaded, being the application home page), a user instruction guide is presented to elucidate the AR camera process and application navigation. At the end of the instructions, a button with a camera icon is provided and it is responsible for opening the AR camera. When it is opened, a process of calibration starts and the camera needs to recognize the horizontal surface on which trees will be placed. This is achieved by circularly moving the phone around and it is complemented by an animation overlayed on the screen representing the necessary movement to help guide the user. Once the surface is detected, an area with white spots will be shown in the AR environment displaying the exact area where tree placement is available.

A menu panel can be toggled by tapping on the bottom right corner button. This menu has many actions and settable parameters accessible to the user, those being: action options for saving a project, undoing the last tree placement, deleting all placed trees; selecting the type of 3D tree model (species) to

[12] Swift is the programming language developed by Apple used to create applications for Apple devices.

[13] Notification Centre is a notification dispatch mechanism of Swift that helps with communication within the application.

be planted; selecting the height of the next tree to be planted; and, finally, selecting the number of trees to be planted at once. This interface can be seen in Figure 5.

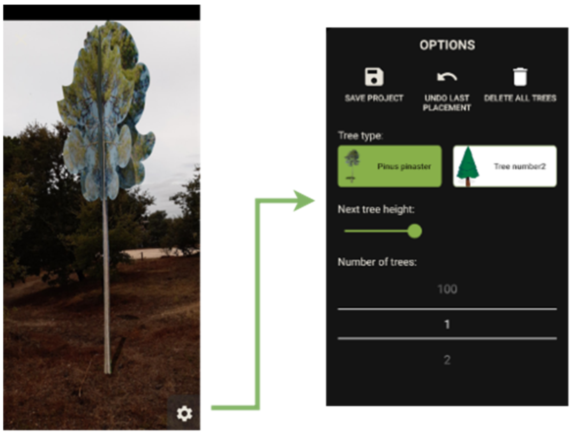

Figure 5: Android ReforestAR AR view.

Differing to ReforestAR for iOS, in Android, the load function is triggered from the Projects Section (not from the AR Section) and when the save option is selected, a dialogue confirmation box is shown asking for the project name and the project description to associate the 3D models' placements disposition (positions in the AR environment) to be saved.

4 DISCUSSION

This section contains an assessment of the proposed architecture, the apps developed for this study and the existing available apps and published scientific work.

4.1 Comparison with Published Apps

After the analysis of similar published applications, a comparison between each application features was conducted, as can be seen in The comparative board includes information about six applications, five of them previously analysed and the last being the study's proposed application.

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ReforestAR, like some of the other contemporary apps, has support for iOS and Android. It includes a feature to create and place 3D objects of trees through AR as the other two applications do but has no carbon footprint control and no 3D object recognition as there were no planned requirements that would utilize these features.

Table 1: Differences of ReforestAR to other applications.

Mobile App	Include different trees species'	iOS and Android Support	Placement of 3D Models in AR	Carbon Footprint Control	3D Object Recognition in AR	Portugal Availability	3D Models Placement Algorithm
Reforest	Yes	Yes	-	Yes	-	-	-
Replant	Yes	-	-	-	-	-	-
RIT	Yes	Yes	-	-	Yes	-	-
TIME Immersive	Yes	Yes	Yes	-	-	Yes	-
WWF Forests	Yes	-	Yes	-	-	-	-
ReforestAR	Yes	Yes	Yes	-	-	Yes	Yes

4.2 Comparison with Scientific Work

After a summary of the exposed ideas from scientific studies in reforestation and AR technology, a discussion about the differences that ReforestAR provides was made.

All the analysed studies had mobile apps developed with Unity using the Vuforia SDK, and two of them confirmed their support for Android devices. What this shows, is that there is a preference for the usage of this software for AR apps for Android OS. Nonetheless, when analysing the published apps, most of them included a version for iOS, something that ReforestAR has also done to reach a large number of users. Two of the analysed studies' applications allowed user interaction with the 3D object, while in ReforestAR object interaction is not allowed. None of the previously analysed studies had the functionality to create more than one 3D object at the same time and ReforestAR does allow it.

The main purpose of all the analysed apps was educational, with a focus on the improvement of the learning of plants and environmental awareness with an interactive alternative for support, much in line with one of the main goals of this project.

5 TESTS AND RESULTS

Following the expected pipeline of interface development, informal tests were conducted with different individuals to correct possible errors and improve user experience. Notwithstanding, at the end of the application development procedure, the System Usability Scale (SUS) questionnaire was applied to obtain a usability score for our application from a group of users that volunteered to test them. The SUS questionnaire contains ten statements that can be scored from 1 to 5, where 1 stands for "Strongly disagree" and 5 for "Strongly agree" (Assistant Secretary for Public Affairs, 2021).

The number of users available for testing varied for each platform and can be considered a small quantity (this is due to the current global pandemic COVID-19), as iOS had four test participants and Android, seven. However, results were useful for the analysis of the usability of the application and future work considerations, even if on a modest scale. Each participant was also informed about the context of the study, the purpose, and the goals that the development of this project attempted to accomplish, thus causing a positive reception in all of them, mostly due to the apps' environmental component.

5.1 Test and Results for iOS

Tests on iOS and iPadOS were conducted. The users could use their mobile devices to experiment the application. The SUS forms were answered in the English language. Participants tested the application indoors and outdoors for ten minutes approximately. In Figure 6, all scores of each question by every participant for the iOS and iPadOS is shown.

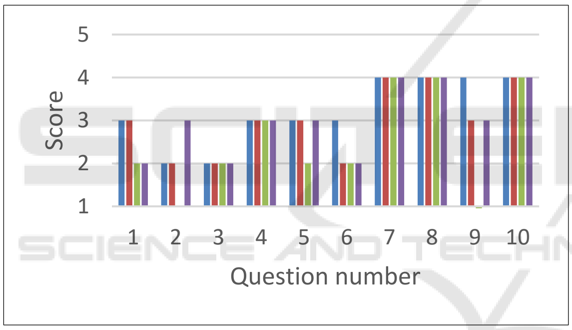

Figure 6: Each question's score by iOS user tests.

The average SUS score of all four participants was 72.5 on a scale between 0 and 100. All participants had an age interval between twenty and thirty years old. Statistically conclusions cannot be done because there were not enough participants, but participants related to the environmental cause were more interested in the study. After being inquired about the operation of the application, answers show that the application's interface was simple to operate, highlighting that the most difficult part to interact with, was using the ReforestAR section.

5.2 Test and Results for Android

As previously stated, due to the global pandemic situation, the number of users that could test this platform were limited, seven to be precise. Four tests were realized by compiling the application on a Samsung A40 device.

The test users were characterized into two age groups, one being "between eighteen and nineteen" and the other, "between fifty-four and sixty-one", with two members in the first group and two members in the second. Members of the second group did not have previous experience with AR.

Another round of tests, this time realized on a Samsung Galaxy S5e 10.5" tablet, was also realized with three participants, all in the age category of "between eighteen and twenty-nine". Navigating and operating the application this time was easier for the participants, presumably due to better hardware specifications of the device used for testing.

After testing the application, participants were asked to answer the SUS questionnaire. The average SUS score of the first age group was 78.5, considered "Good", and for the second one, 84, also considered "Good" in adjective ratings (Bangor, 2009). Figure 7 demonstrates each question's score by a participant.

After being inquired about the ease of navigation and operation of the application, most participants stated that they thought the interface was very simple to operate and that the most difficult part of the operation was when using the AR camera but agreed that most people would learn to use this system very quickly.

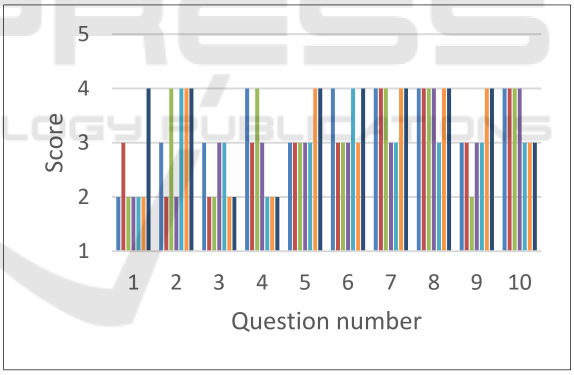

Figure 7: Each question's score by Android user tests.

6 CONCLUSIONS

This study had the purpose of developing mobile applications, both for iOS and Android platforms, that could assist users to experience what reforesting trees could look like, and beyond the successful development, there were satisfactory user tests. The concise feedback received from these tests showed that all the users that operated the applications found them accessible and easy to use, despite a need for an initial short learning time.

The difference in the general score for both apps may be attributed to differences in layout and possibly due to the Android application having instructions on how to operate it. This might indicate that instructions are vital for a better user experience.

The authors intend that ReforestAR for iOS and Android can assist in reforesting lost areas with its planning capabilities and become widely used.

Considering that this application is at an initial proposal state, future work on this project is contemplatable. It can include saving and loading 3D models according to geolocation placement values, more configuration parameters for the AR camera interface, a more realistic placement algorithm that considers each species' minimum placement distances, a carbon footprint calculator for projects according to the number of trees, and a tutorial view for the iOS platform.

Hopefully, when ReforestAR becomes available to the general public, the interactive experience of planting virtual trees can bring their attention to the topic of deforestation and reforestation, and consequently, raise awareness of these sensitive topics.

Since real-world reforestation projects tend to have visible results only after a couple of years, we believe that the immediate nature of viewing a tree in a deforested zone through ReforestAR can help motivate users to this subject.

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