Situational Awareness-based Augmented Reality Instructional (ARI) Module for Building Evacuation

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ABSTRACT

Emergency response in indoor building evacuation is essential for effective rescue and safety management. First responders often lack the situational awareness capability to quickly assess the layout of a building upon initial entry. For occupants of the building, situational awareness becomes more important in cases of active shooter events or circumstances of fire and smoke. One of the challenges is to provide user-specific personalized evacuation routes in real-time. In multilevel building environments, the complexity of the architecture creates problems for both visual and mental representation of the 3D spaces. This paper presents three cutting edge Augmented Reality Instructional (ARI) modules that overcome the visual limitations associated with the traditional, static 2D methods of communicating evacuation plans for multilevel buildings. Using existing building features, the authors demonstrate how the three modules provide contextualized 3D visualizations that promote and support spatial knowledge acquisition and cognitive mapping thereby enhancing situational awareness. These ARI visualizations are developed for first responders and building occupants to help increase emergency preparedness and mitigate the evacuation related risks in multilevel building rescues and safety management. Specifically, the paper describes the design and implementation of the ARI modules and reports the results of the pilot studies conducted to evaluate their perceived usefulness, ease-of-use, and usability. The results suggest the desirability of further heuristic examination of three-dimensional situational awareness-based ARI application effectiveness in multilevel building evacuations.

Keywords: Augmented reality, indoor evacuation, emergency management, two-dimensional/three-dimensional visualizations.

Index Terms: Human-centered computing—Visualization—Augmented Reality—Building evacuation—Situational awareness—Visualization design and evaluation method

1 INTRODUCTION

Emergency preparedness is an important element of emergency management and involves planning appropriate responses to hazardous events. To protect public safety, it is critical that emergency plans are communicated to both building occupants and first responders both timely and accurately. The technology of modern smartphones offers a platform with which first responders could provide 3D representations that preserve the topology of multi-level built environments by adding the spatial context that allows the individual to better understand the building evacuation plan and available exits. The research work introduces situational awareness-based Augmented Reality Instructional (ARI) modules for 3D visualizations in the multilevel building as a method to communicate building evacuation plans and increase locational cognizance for all building occupants. This paper presents location awareness in multilevel spaces by generating ARI visualizations which are three dimensional spatially contextualized communication of evacuation plans.

The three-dimensional visualizations utilized by the three ARI modules presented herein permit building occupants to be able to evacuate multilevel buildings in emergency circumstances by enhancing situational awareness through promoting spatial knowledge and cognitive mapping to a greater degree than do two-dimensional visualizations. Building managers oftentimes mount 2D evacuation maps throughout the building, among other things. However, the issue with these 2D maps is that they do not provide the deep perspective that 3D maps offer, that is, a perspective that would enable building patrons to accurately see specific features such as room entrances, hallway corners, stairs, and the like. A 2D map, which merely provides a building's outline, lacks this characteristic. Further, 2D evacuation maps require users to recall or remember the path to safety. Retaining memory of a building's outline as well as the necessary evacuation path could prove to be difficult, especially in a stressful, urgent emergency evacuation situation.

Recognizing these limitations of 2D evacuation maps, situational awareness-based ARI modules were developed herein to help users evacuate a building in the event of a fire, smoke, earthquake, or active shooter emergencies. Each of these three modules features image markers that are used to generate a 3D floorplan visualization when a device camera is pointed toward a relevant marker. The novelty of this approach lies in using existing building features to provide user-specific personalized evacuation routes in real-time for supporting spatial knowledge acquisition and cognitive mapping. This idea is applied by using a special set of visual cues, termed *intelligent signs*, which help the user locate each exit and the path to such exit. Examples of intelligent signs used in this work are indicators pinpointing building entrances, photographs of specific locations in the building, and arrows tracing the path to the exits. Besides, each module displays pertinent information when a 3D floorplan has been generated, such as room numbers to further assist the user in ascertaining their present location (or bearings) while evacuating as shown in Figure 1.

Figure 1: 2D evacuation plans mounted throughout a building serve as markers for the ARI modules.

Indoor emergency evacuation plans in a building exist to increase the chances of survival in an emergency. Evacuation drills are needed to ensure that these plans work efficiently.

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According to Pandolfo [1], evacuation drills reduce the anxiety and panic that may be experienced during an emergency. Additionally, evacuation drills must be conducted often to help participants retain the knowledge of the proper evacuation procedures and must mirror real emergencies as much as possible so that participants can be truly prepared to evacuate safely when the time comes [1]. Unfortunately, live evacuation drills fail sometimes because participants may not have the time nor the physical ability to participate in drills [2]. Augmented reality (AR) has been widely used to teach users a particular concept since it offers a captivating learning environment where computer-generated objects are combined with users' physical surroundings [3]. AR also promotes imagination and immersion so that users can interact with the objects to obtain the desired view of the environment [4]. The combination of imagination and immersion helps users to not only gain knowledge but also to retain what was learned. Sharma *et al.* [5-8] have used AR for developing an emergency response system for building navigation and evacuation.

The rest of the paper is organized as follows: Section 2 discusses studies related to the one reported in this paper; Section 3 details the system architecture of the application; Section 4 describes the implementation of the application; Section 5 addresses the user study evaluating the application as well as the results of that study; and Section 6 concludes this paper and gives ideas for future work regarding this study.

2 Related Work

2.1 AR in Education and Instruction

A system teaching paramedic trainees how to perform direct laryngoscopy (examination of the larynx) with foreign body removal was proposed by Birt *et al.* [9]. Users interacted with the system by wearing a hat with a mobile phone (which, presumably had the application installed on it) situated on its bill. A virtual patient laid in front of the user with an open mouth, enabling the user to perform the procedure using 3D printed tools, namely, laryngoscope, Macintosh blade, and Magill forceps. Blum et al [10] implemented mirracle – an AR system that projected a simulated CT scan and superimposed it on the user, making the user feel as though he or she is looking at a CT scan of his or her own body. The simulated CT scan was constructed from the Visible Korean Human dataset. The system also displayed text-based information about the organs and diagrams of them and rendered the text and diagrams on a "frosted glass" background. A demo of this system, built for Microsoft Kinect, received positive feedback from participants. De Ribaupierre *et al*. [11] developed an AR system training users on how to conduct an external ventricular drain (EVD), a medical procedure where a patient's intracranial pressure was relieved through draining the cerebrospinal fluid. A NeuroTouch simulator was used as a part of the AR system and was comprised of a mannequin head and pointing tool. A simulated volumetric scan was superimposed on the head and the juxtaposition of the scan with the head was seen on the user interface when the user pointed a tablet's camera to the head. Ienaga *et al.* [12] developed an AR application for the Kinect that taught anatomy through the use of diminished reality where an object was detected by a camera during a video stream and eliminated. As a result, the user could see through the area where the object was. Eckhoff *et al*. [13] implemented TutAR for medical education. TutAR took in as input, via video, hand motion and generated a 3D hand that used animation mimicking the given hand motion. The 3D hand's position corresponded to the mannequin that the user was using and the motion in the video.

Dontschewa *et al.* [14] implemented a HoloLens application where the user drops a 3D rigid object – a ball through a guide tube. As Dontschewa et al describe, the ball fell freely when dropped in a space but when the ball was dropped through the tube, the ball was restricted to falling through the path constructed by the tube. The work described in [14] demonstrated interaction with 3D objects and "spatial placing" using HoloLens. Guhl *et al*. [15] implemented an application for HoloLens which enabled the user to interface with a robot so that the robot could carry out an action given (e.g. grab an object) and navigate on a path defined by the user. When the HoloLens recognized a marker associated with the application, a 3D replica of a robot was generated within the user's physical environment. Chen *et al.* [16] developed an application for which AR markers are placed on pages in a textbook. The pages contained 2D drawings of objects such as worming wheels. When the user pointed the device camera at the markers, a 3D model of the 2D drawing was superimposed upon the page. Kommera *et al*. [17] developed an application for a brand of smart glasses known as Vuzix. The application aimed to increase the users' interest in cybersecurity education by extracting (from articles, feeds, and alerts) data suggesting that a cyber-attack had occurred, reducing the work the user had to do in extracting the same information manually.

Ku era *et al.* [18] discussed a project involving the use of Microsoft HoloLens to teach a concept, specifically, an AR application where the user viewed a 3D model of an electric kart along with a description of its parts. Pittman and LaViola [19] developed a HoloLens application named HoloPhysics which aimed to teach users physics concepts – namely, elastic collisions, parallel circuits, and electrical fields. Hanna *et al.* [20] reported a study where the HoloLens was used by pathologists to conduct procedures such as an autopsy, dissecting specimens, and volumetric pathology. These procedures were supplemented by 3D images of organs and by radiographs superimposed on real organs. The organs and radiographs were displayed on the HoloLens. According to Hanna et al, pathologists and pathology assistants could manipulate the virtual environment without difficulty for a wide variety of clinical and nonclinical tasks. Zareen and Ghulamani [21] gave a questionnaire to 200 people regarding the quality of education in remote areas and their impressions on whether or not HoloLens was more effective than traditional methods of education (i.e. lecturing). Half (50%) of the survey takers said that the quality of education is low in remote areas and most of them preferred the teaching via HoloLens over traditional methods of education. Zareen and Ghulamani, in their paper, suggested that HoloLens would improve the quality of education in remote areas and help teachers in those areas teach better.

2.2 AR in Building Evacuation

Iguchi *et al*. [22] implemented an AR system training adult users to communicate to children during emergency evacuations. Users interfaced with the system using Google Cardboard. The system employed virtual children with which the users communicated via voice interaction. Ahn and Han [23] proposed RescueMe, an AR system that enabled users to obtain their locations by photographing a room number. RescueMe also calculated the user's stride as well as suggested, to the user, the most succinct way to the exit. A simulation evaluating RescueMe compared the evacuation time (in ticks) of its algorithm with the evacuation time of a shortest path algorithm and randomization (when no algorithm is used to navigate an environment). The simulation determined that the RescueMe algorithm took the shortest time when compared to the other two algorithms. Lastly, Mitsuhara *et al.* [24] developed an AR system that affixed computer-generated elements such as an injured person, rain, fog, smoke, fire, and damaged vehicles onto the physical environment to emulate real-life emergencies warranting evacuation.

Vold *et al*. [25] used Microsoft HoloLens for emergency management in a study applying a concept known as "flipped gaming" where students discussed learning activities with each other and the instructor acts as a "facilitator". In this study, the students were placed into different groups and were tasked with coming up with crisis scenarios. After one group completed a scenario, they gave it to another group to execute using either one of three platforms: VBS3 (Virtual Battle Space 3), the HoloLens, and Rayvn. The study results proved that HoloLens could be used for indoor evacuation as well as for crisis management. Another study, discussed by Chusetthagarn et al [26], utilized a HoloLens application featuring a 3D map of Japan and a menu where the user could show and hide meterological information (i.e. rain and snow) and geographical details (i.e. dams, water, and shorelines). The application implemented in [26] served to determine which region in Japan is in danger and relayed that information (and related details) to the user so that the user may prepare to evacuate the vicinity. Li et al [27] have used safety training through virtual drills by using virtual reality.

3 SYSTEM ARCHITECTURE

This section describes the development of the three versions of the ARI modules. Version 1 was designed for mobile phones and tablets while Versions 2 and 3 were designed for phones, tablets, and HoloLens.

3.1 Version 1

The system architecture for Version 1 of the module is illustrated in Figure 2. This Version is compatible with both mobile phones and tablets. The user carries a mobile device with the application installed on it (represented by "Mobile Device" in the figure). The user points the device camera to a marker which is recognized by the device after which a 3D floorplan is generated and superimposed atop the marker, formulating the display that the user sees. The 3D floorplan not only consists of a computer-drawn version of a 2D floorplan, but also three features: the intelligent signs, virtual fire and smoke, and avatars. The user interface (represented by "AR Environment" in Figure 2) consists of toggle buttons that the user may use to show or hide these features and the developers' information (i.e. name and university affiliation). There are two additional buttons that the user may use to zoom in on the floorplan and to zoom out of the floorplan. The 3D floorplan and the toggle buttons formulate the output which the user sees when the device is pointed toward the marker.

3.1.1 Mobile Phone Used for Version 1

The mobile phone used for Version 1 of the ARI module was the LG G7 ThinQ. The phone features a 16-megapixel rear camera (the camera utilized by the module), 3120x1440 pixel display, 4 gigabytes of RAM, an 8-core CPU, an accelerometer, and gyroscope. The phone operates the "Pie" release of the Android operating system. Samsung Galaxy Note 9 and S9 were also used for testing the ARI module.

3.1.2 Tablet Used for Version 1

The tablet used for testing Version 1 of the ARI module was the Samsung Galaxy Tab S5e. The tablet features a 13-megapixel rear camera, 2560x1600 pixel display, 6 gigabytes of RAM, and an 8-core CPU. Similar to the mobile version, the tablet also runs the "Pie" version of the Android operating system.

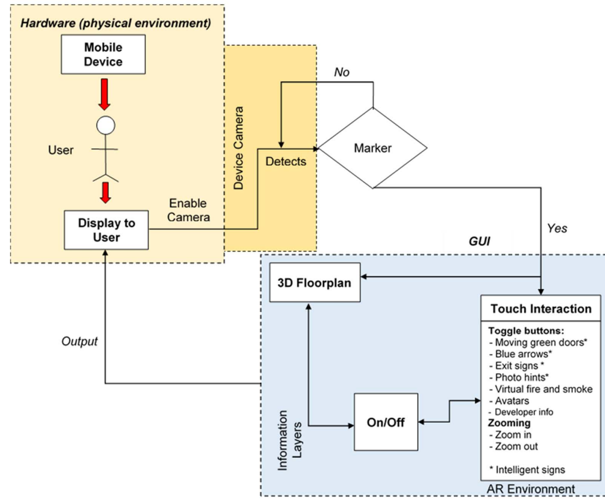

Figure 2: System Architecture for Version 1 of the module.

3.2 Versions 2 and 3

The system architecture of Version 2 and 3 is shown in Figure 3. The mobile devices used for these versions of the ARI module were Samsung Galaxy Tab S5e, Samsung Galaxy Note 9 and S9. The application was loaded onto the targeted device such as a phone, tablet, or HoloLens. With the installed application running on the device, the user can view his or her surroundings using the camera embedded on the device. Existing building features, such as signboards, have been used to provide user-specific personalized evacuation routes with arrows directing the user to the nearest exit. The buttons are added in Versions 2 and 3 to add more layers of information such as room numbers.

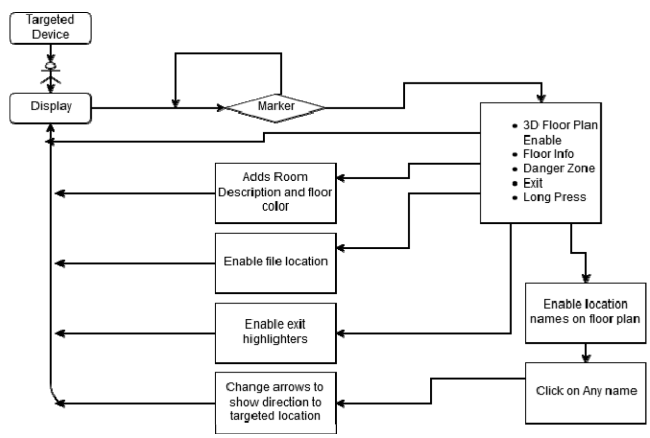

Figure 3: System Architecture for Versions 2 and 3 of the module.

3.2.1 HoloLens

HoloLens is a pair of smart glasses designed to run mixed reality applications. When running, the device embeds computer-generated graphics within the physical environment which the user sees, giving the user a holographic interface with which the user interacts to use applications installed on the HoloLens. Essentially, users can still view the real-world in front of them while interacting with the device.

HoloLens is comprised of an Intel Cherry Trail System on Chip (SoC) and a Microsoft Holographic Processing Unit made specifically for the HoloLens. It also offers a 2GB RAM for processing data. To simplify the interaction between it and the user, the HoloLens incorporates hand gestures and voice commands as input and has a clicker for interaction. HoloLens has four environment sensors (two on each side) designed to sense the environment surrounding the user and to track and identify hand gestures and the orientation of the headset. The HoloLens offers an energy-efficient depth camera with a 120° x 120° angle of view, which helps in rendering the surroundings and identifying different surfaces in the environment. Above the depth camera, there is a 2.4 megapixel photographic and video graphic camera that captures videos and images of the user's surroundings.

4 Implementation

Figure 4 illustrates the implementation of the versions of the ARI module. These modules are implemented to help users evacuate the building by providing spatially contextualized 3D visualizations and personalized evacuation routes. The implementation of the ARI modules began with the designing of the 3D floorplans and other models using SketchUp and 3dsMax. This step was followed by the implementation of the modules' functionality using Unity before they were packaged into an executable file and transferred onto the target device for installation.

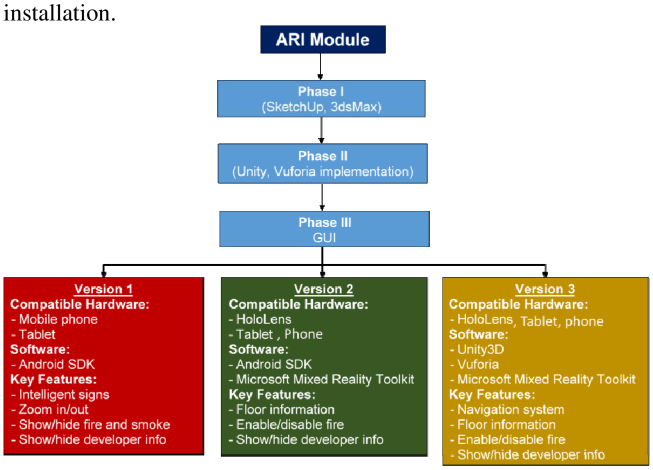

Figure 4: Implementation for the ARI module.

4.1 Phase I

In the first phase of implementation, SketchUp was used to model the 3D floorplans. The floorplans were modeled from 2D floorplans of the Computer Science Building on campus, which were obtained before implementation (refer See Figure 5). Objects such as tables, desks, boards, chairs, and computers were added for adding realism.

Figure 5: First floor of the Building being drawn in Sketch Up.

Additionally, textures were added onto the floorplans and objects. Attention was paid to ensure that the file size of each 3D floorplan was not too large to be used in Unity for the next phase. Once the floors were modeled, they were exported into Unity so that they might be incorporated in the ARI module for the next phase.

4.2 Phase II

During this phase, the floorplans modeled in the previous phase were brought into a scene in Unity 3D. There, the floors were placed upon their respective markers so that the proper floor could be detected when the device camera is pointed at a marker. Version 1 of the ARI module used three different types of markers (all shown in Figure 6): Type A, paper-based image markers, were self-generated to augment the 3D floors in the building; Type B, existing signboards mounted in front of entranceways throughout the building containing room numbers and names, were also used to augment the 3D floors in the building; and Type C were static objects located in the building such as signboards, ATM machines, vending machines, posters, fire extinguishers, and alarm systems.

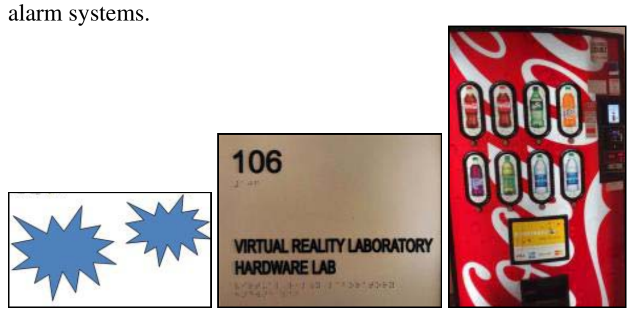

Figure 6: Three types of markers used in 3 Versions (from left to right): Type A, Type B, and Type C.

Pictures of existing signboards mounted around the ground floor were taken and loaded into Vuforia as image markers. From Vuforia, a database of these markers were downloaded into Unity so that the application can recognize them when they are detected by the camera. When the camera detects the markers, the application juxtaposes the appropriate floorplan above the markers.

4.3 Phase III

4.3.1 Version 1

In this version, on each floor, avatars were placed to help guide the user to the exits. Each avatar was assigned different speeds and paths with which to navigate towards the exits. Each floor was also equipped with virtual fire and smoke, which evokes a sense of urgency within the user. Lastly, each floor features four intelligent signs. The signs (shown in Figure 7) help users locate the exits and the path towards those exits. The intelligent signs, and their descriptions are as follows:

- Blinking Exit Signs – Cubes that read "Exit Here!!!" in red letters located at each exit and move up and down on a continuous loop
- Moving Green Doors – Thin green cubes located at each door leading outside the building; the cubes move from left to right on a continuous loop
- Blue Arrows – Arrows situated on the floor tracing a path to an exit; this sign was inspired by the floor arrows seen in Ikea stores
- Photo Hints – Pictures of specific points on the floor that serve to help users identify their locations; in the interface, the Photo Hints are located at their corresponding locations on the floor

The user may use the toggle buttons located on the left side of the display to show and hide the signs as needed and to zoom in and out of the floor.

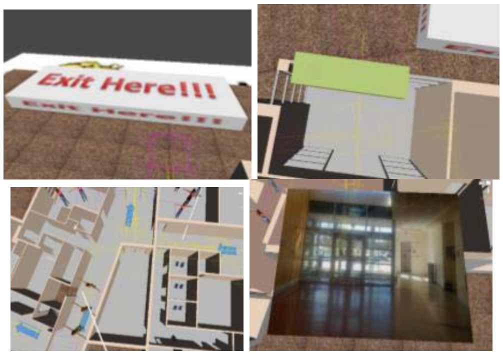

Figure 7: Intelligent signs used in Version 1 (clockwise from top left): Blinking Exit Signs, Moving Green Doors, Blue Arrows, and Photo Hints.

After the scene was fully constructed, this version was packaged into a apk file so that it may be installed on Android-based mobile devices. The user interface of Version 1 of the module can be seen in Figure 8.

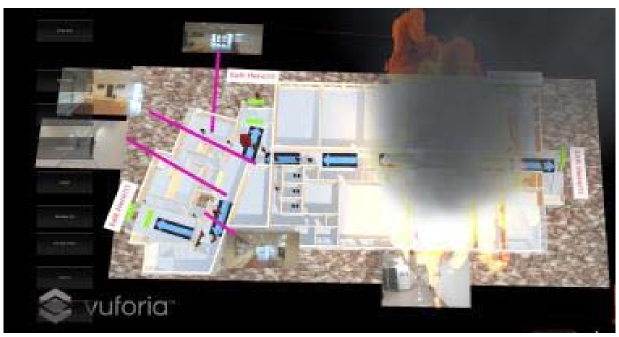

Figure 8: The user interface of Version 1 of the ARI module.

4.3.2 Version 2

In this Version, C# scripts were implemented to add functionality for the buttons and to show and hide the green arrows seen in the user interface via Unity 3D (refer to Figure 9). Assets such as the Vuforia toolkit and the marker database were imported. The main camera in Unity was replaced with an AR camera. The license key from Vuforia was used to activate the camera and to give the camera access to the marker database. In Unity, several image markers were used to assign the floorplans by placing each floorplan above its corresponding marker in a Unity scene. This arrangement of floorplans above the markers guarantees that the correct floorplan is shown when a given marker has been detected by the camera. The arrows were placed on each floor to trace each possible path to the exit. These arrows are initially disabled (hidden) but become enabled (shown) based on the signboard detected by the camera. The arrows are controlled by a C# script. When a signboard has been detected, the respective floor plan will display with arrows directing towards nearest exits along with a red dot indicated the user's current position on the floorplan.

For Version 2, three buttons were created to manage the functionality of the application. One button was for enabling and disabling the virtual fire on the floor plan to let users know where the emergency is located. A second button was developed to enable and disable the room numbers and their descriptions. When enabled, the room numbers were added above the floor plan in the appropriate places so that users can use this application to familiarize themselves with the building, not just to evacuate. Lastly, the third button was used to display the developer's information. Initially, when the application is opened in the device, real-time camera view is open. Once the camera detects a signboard in the building, it displays the floorplan with the current location, arrows enabled, directing the user towards the nearest exit as seen in Figure 9.

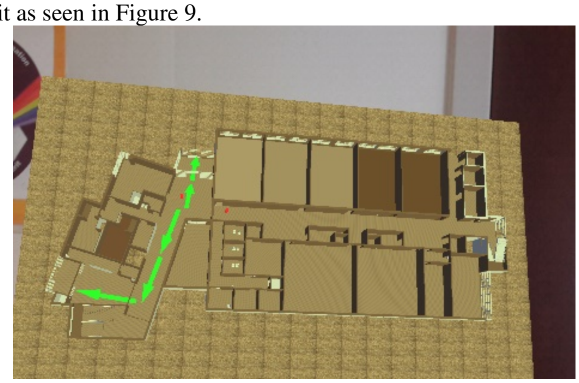

Figure 9: Version 2 of the ARI module.

4.3.3 Version 3

In this phase, buttons were added above the floorplan for best viewing in HoloLens since the floorplan was programmed to always stay below the center of the screen. A color layer was also added along with the floor numbers to differentiate the rooms so that when the room numbers are shown, the layer identifies the rooms more easily. The pinch hand gesture was used to zoom in and zoom out of the 3D floorplan. A similar option was enabled for tablets and mobile devices. In HoloLens, the size of the 3D floor plans is automatically adjusted according to the eye covering the area.

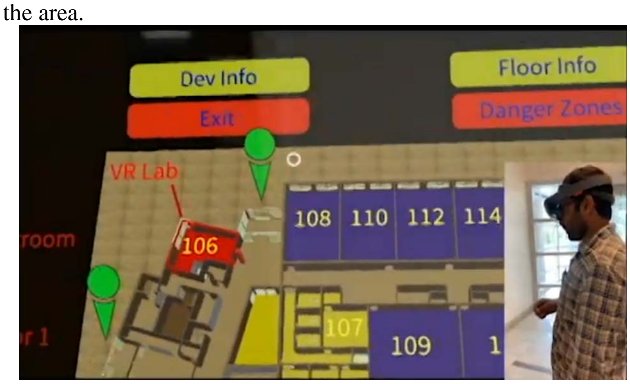

Figure 10: Version 3 of the ARI module.

Another functionality added in this Version was indoor navigation. Once the floor plan appears, the user has the option to enable different layers to add more contextualized information to the floor plans. By default, the arrows guide the user toward the nearest exit(s), but when the user selects a room name, the arrows will show the user the direction to that room from the current location. Thus, the user can also use this application not only for emergency evacuation but also for general indoor navigation.

This Version of the ARI module was deployed onto Android devices (phones and tablets) and the HoloLens. Before deploying onto the devices, Android was indicated as the target platform and the SDK version was selected in Unity's build settings and player settings menu. For deployment onto the HoloLens, Windows was selected to be the target platform. Once Unity built the application for Unity, a Visual Studio solution was generated for the application. From Visual Studio, the target device was selected to be HoloLens. The application was then deployed onto it. The implementation process for this Version is shown in Figure 11.

Figure 11: Implementation for Version 3 of the module.

5 Evaluation & Results

The ARI modules were evaluated in a real-life scenario for version 1 and version 3.

5.1 Version 1

5.1.1 Evaluation Framework

Version 1 of the ARI module was evaluated through a user study utilizing two framework components: The Technology Acceptance Model (TAM) and the System Usability Scale (SUS). The TAM was utilized to measure users' perception of the ease of use and usefulness of a given system. As discussed by Chuttur in [28], it is composed of twelve Likert-scale items – six items assessing users' perception of ease of use and six items assessing users' perception of the system's usefulness. Each item is given a rating using a seven-point scale where the lowest end represents "likely" and the highest end represents "unlikely". The SUS measures a given system's usability. According to Lewis and Sauro [29], it utilizes ten Likert-scale items, each rated on a scale of 1 to 5 where 1 represents "strongly agree" and 5 represents "strongly disagree". A score contribution ranging from 0 to 4 is assigned to each item. All responses are totaled to obtain a SUS score between 0 and 100. The computation of the SUS score is as follows:

1. Subtract 1 from the score contributions for odd-numbered questions.
2. Subtract the score contributions for even-numbered questions from 5.
3. Add all of the contributions together and multiply the sum by 2.5.

5.1.2 User Study

The user study involved 69 participants divided into two groups: insiders and outsiders. Insiders refer to participants who visit frequently the Computer Science building either for work or classes. Outsiders refer to participants who do not visit frequently the Computer Science building. Recruiting study participants involved seeking permission from instructors and office managers on campus so that the students in the classes and the employees in the offices might participate in the study. Upon being granted permission, selected classes and offices around campus were visited to conduct the study. At the beginning of each session, participants were shown a demonstration of how to use the module. Then, the users were given the module and asked to use the application to evacuate the building (after signing a consent form). The users viewed the 3D representation of the building, direction to the exit, and their location, which were triggered through the existing markers (refer figure 6) in the building. The participants first held a mobile phone over the markers, then held a tablet over the markers with the ARI module installed on it. When either the tablet or the mobile phone detected the markers, the participants were able to see the corresponding 3D floorplans and all of the toggle buttons to the left of the floorplans. After each participant used the module, he or she answered a questionnaire based on the TAM and SUS frameworks as well as questions obtaining demographic information.

5.1.3 Results and Implications

According to the study data, 46% of the participants were male and the other 54% were female. Over half the participants (55%) were insiders while 45% were outsiders. All the participants were at least 18 years of age. As seen in Figure 12, 85% of the participants were students and the remaining 15% were either staff, faculty, or administration. A majority of the participants, 97%, reported having at least some experience using mobile applications, as seen in Figure 13.

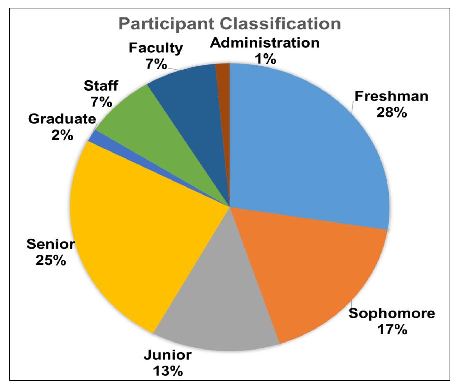

Figure 12: Demographic breakdown for the user study evaluating Version 1.

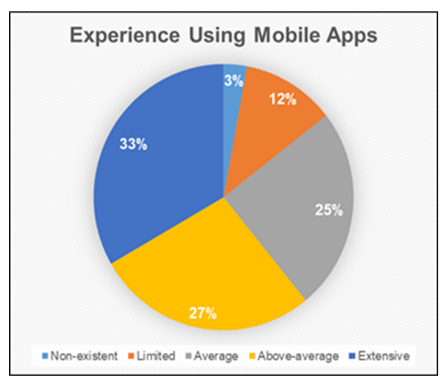

Figure 13: User study participants' experience in using mobile apps.

Other than the questions obtaining the demographic information about participants, there were three other sets of questions in the questionnaire: one set derived from the SUS, another from the TAM, and the third set of questions specific to the module. Specifically, the last set of questions required participants to compare the 3D module's effectiveness in helping users evacuate with similar effectiveness and use as a guide of the 2D evacuation plan.

A correspondence between SUS scores between 0 and 100 was made by Bangor et al in [30] with the collegiate grading scale whereas a SUS score of 100 equals "Best Imaginable", 85 to 99 equals "Excellent", 75 to 84 equals "Good", 52 to 74 equals "OK", 48 to 51 equals "Poor", and 25 to 47 equals "Worst Imaginable". The SUS score for all the responses were calculated as described in Section 5.1.1. The SUS scores for all the questionnaires were then averaged to obtain a SUS score of 65.61594 which corresponds with "OK", according to the scale devised by Bangor et al. The obtained average SUS score suggests that Version 1 of the module has usability that is acceptable to users.

The responses to each of the second set of questions (those based on the TAM) were averaged as well. The averages for each question in that set ranged from 2.6 to 2.9 meaning that they would correspond to a qualitative value of "Somewhat Likely" on the TAM scale (if rounded up) seeing as 1 corresponds to "Likely" and 7 corresponds to "Unlikely". The numerical scores and their corresponding qualitative values as used in the questionnaire are given in Table I. This result suggests that Version 1 is useful in helping evacuators in the event of an emergency and that it is easy to use.

Score	Qualitative Value	
7	*Very*	**Unlikely**
6	*Quite*	
5	*Somewhat*	
4	*Neutral*	
3	*Somewhat*	
2	*Quite*	
1	*Very*	**Likely**

Table I: Numerical scores and their corresponding qualitative values for the TAM.

Finally, the averages of each set of questions for the third set of questions were calculated. That set of questions used a five-point Likert scale where 1 = "Strongly Disagree", 2 = "Disagree", 3 = "Neutral", 4 = "Agree", and 5 = "Strongly Agree". The averages for each question in that set corresponded to "Neutral", which contrasts the averages of the other two sets of questions. However, the mode (the most popular response) for the third set of questions suggests that users will likely find Version 1 of the module to be useful in guiding their evacuations and will likely use it to help them evacuate rather than a 2D evacuation plan. The mode for the first question, as shown in Table II, was 5 (or "Strongly Agree") and the modes for the other two questions were 4 (or "Agree").

Question	Mode
1) I would use the ARI module to help me evacuate the building during a real emergency.	5
2) I would more likely use the ARI module and its panoramic view rather than posted exit signs and evacuation plans in 2D.	4
3) I believe the ARI module will enhance my awareness of exit strategies in buildings.	4

Table II: Modes for the third set of questions evaluating Version 1.

5.2 Versions 3

A limited user study was performed for Versions 3, involving ten participants. Initially, the participants were shown how to use the ARI module on the tablet and on the HoloLens. Then, each participant was allowed to use each device, personally. The evaluation process consisted of two steps. Initially, the participants try to leave the building while using the ARI module in the emergency context. Then, they are given a satisfaction questionnaire about the overall experience. All of the questions, except for one, permitted a Likert response bipolar scaling with an interval from 1 to 5. The other question, which asked the participants' which device (tablet or HoloLens) was the most suitable for the module, using a Likert scale with an interval of 1 to 10. After using the module on the tablet and the HoloLens, the participants answered the questionnaire regarding their perceptions of this Version's usability and effectiveness. The user study was composed of 80% male participants and 20% female participants. The responses to the four hypothesis questions are given in Figure 14. The four hypothesis questions inquired:

- Whether Versions 3 was useful in unknown buildings with a complex structure.
- Whether viewing the module in the HoloLens help during real-time evacuation.
- Whether Versions 3 was a substitute for 2D evacuation plans in a building.
- Whether Versions 3 was useful for educational or training purposes.

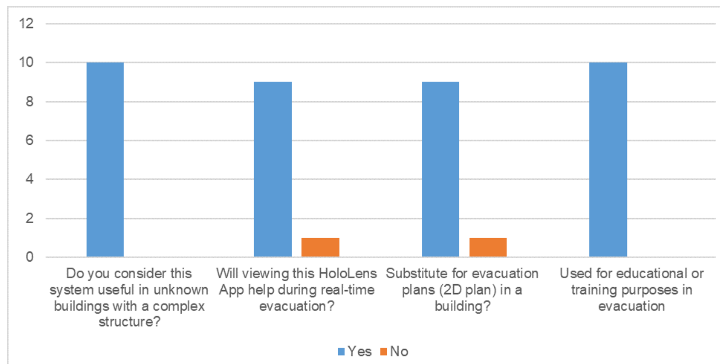

Figure 14: Questionnaire results for user study Versions 3.

Figure 15 indicates that the majority of the users felt that the HoloLens was more suitable for evacuation than the tablet or mobile phone.

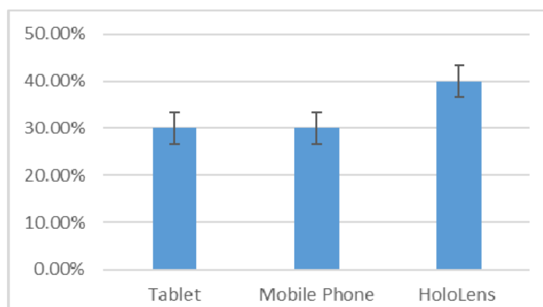

Figure 15: Device suitability and effectiveness, of the ARI module (tablet, mobile phone, and HoloLens).

6 Conclusion

This paper presents location awareness in multilevel spaces by generating ARI visualizations for spatially contextualized communication of evacuation plans. An ARI module was developed to help users evacuate a building in case of an emergency. Three versions of the ARI module were built: Version 1 was built for Android tablets and mobile phones; Version 2 was built for Android tablets, phones, and the Microsoft HoloLens; and Version 3 was built for Android tablets, mobile phones, and the HoloLens. It featured 3D floorplans derived from obtained 2D floorplans of the Computer Science Building on campus. The 3D floorplans were drawn using SketchUp and 3dsMax. The models were imported into Unity where they each had avatars, virtual fire and smoke, intelligent signs, and other visual cues added onto them. Additional functionalities such as the touch/toggle buttons used in all the versions were implemented in Unity. Upon completion, the ARI module was packaged into an executable file compatible with the target device and installed on the device. The user studies demonstrated that the ARI module is not only user-friendly but also is effective at helping building patrons evacuate a building. It is worth noting that occupants unfamiliar with a building may find these modules especially useful in guiding them in their evacuations due to improved spatial perception and cognitive mapping. The responses from the user studies confirmed our four hypothesis questions 1) Versions 3 was useful in unknown buildings with a complex structure; 2) Viewing the module in the HoloLens will be helpful during real-time evacuation; 3) Versions 3 would act as a substitute for 2D evacuation plans in a building; 4) Versions 3 was useful for educational or training purposes.

The results from the user studies indicated that the ARI modules in Versions 3 was useful in helping people evacuate buildings and can be used as a substitute for 2D evacuation plans. However, our user study did not compare our proposed ARI module with exisiting 2D paper evaucation plan. The reason for this was that these days most of the people carry smart phones and do not carry paper evacuation plan of a building. However, 2D evacuation plans are displayed at key places in the building that can ne used as a marker to triger 3D evaucation plans through the smart phones. Our future work will include conducting more user studies that are applicable to the real-world situations by incorporating more details like: comparison with 2D paper plan, time to exit, number of errors, wrong turns, etc. Lastly, comparing the HoloLens to the tablet, 40% of the participants thought that the HoloLens was the most suited device for the module while 30% thought that the tablet was the most suitable device and 30% thought that the mobile phone was more suitable. The HoloLens was preferred because when it is being used, one can view the real world while interacting with the module resulting in an uninterrupted view of that person's surroundings whereas, with the tablet, one has to turn his or her attention to the display on the tablet and then has to gather his or her bearings within the surrounding environment after interacting with the module on the tablet.

One the limitations of our work is that the proposed ARI modules might be unusable under the environment of smoke, blackout at night, and when fire sprinkler system is activated. Future work with the ARI modules includes more user studies to further validate its ease-of-use and usefulness, to see how demographics perceive these modules, usefulness between 2D-3D information display, and to gather open-ended feedback to help enhance these modules' performance. Future work also includes considering and factoring in regulatory rules in design and implementation; and developing the module to be compatible with devices running other operating systems such as iOS or Windows. Also further work will include implementing a generalized neural network algorithm to link location, markers with target 3D content for a new building.

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