COMP9700 – Master's Thesis

DESIGN AND DEVELOPMENT OF A HANDHELD AUGMENTED REALITY SERIOUS GAME FOR INTERACTIVE BUSHFIRE RESPONSE SIMULATION

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Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Ngoc Anh Ly

6th November 2020

Abstract

Bushfire in Australia has been causing devastating damage to people, infrastructure, housing, animals and their habitats. It is crucial to raise awareness of bushfire and the importance of bushfire responses. Many fire-fighting organisations have been tackling this problem with different approaches but only focused on traditional media such as websites, guides, and physical activities. Serious games are games developed not just for entertainment purpose. Handheld augmented reality is growing fast and is attractive to mobile savvy audiences. This thesis presents the design and development of a handheld augmented reality, serious game for interactive bushfire response simulation named BushfireAR. The initial research question of the thesis is: Can a serious game increase awareness regarding bushfire in Australia? The literature review section of this thesis summarises research on bushfire, serious games, and handheld augmented reality. The design and development sections discuss BusfireAR's concepts, prototypes, design decisions, and implementations. BushfireAR represents the characteristics of bushfire in a game environment, introduces the players to five different bushfire scenarios demonstrating different bushfire complexity, and gives the players direct control over a fire truck to handle bushfire incidents. The game incorporates visual and audio elements with educational information transfer. The design and development then followed by a pilot evaluation with 12 participants. The survey combined questions about participants' demographics, bushfire awareness, and handheld augmented reality usability. The final results implied a high satisfactory in augmented reality usability but neutral on raising bushfire awareness, suggesting the need for future work covering extensive design, development, and evaluation.

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Section 1: Introduction

Bushfire is a severe problem in Australia. Every year, bushfires cause damage resulting in huge economic, social, and ecological costs. Combining with the unpredictable climate changes every year, the damage bushfires cause is now increasing at an alarming rate. Bushfire is becoming one of the biggest Australian crises. Due to both natural and artificial causes of bushfire, it has become a regular occurrence. Thus, preparation for bushfire is a crucial task. But doing physical training with just vehicles and firefighting equipment is not enough. Moreover, bushfire response is not solely firefighters' responsibility. In this project, a serious game as an interactive simulation with support of augmented reality will provide a comprehensive approach to tackle the bushfire problem, immerse the user into the simulation scenario, and give the user an overall look as well as direct responsibility to the given bushfire scenarios. By doing so, the simulation can provide an instructional experience for the player and seeks to improve bushfire awareness for young children. This thesis will start by introducing Project motivation and key areas in Section 2. This will follow with Literature review in Section 3 to review related research areas and inform the benefits of the project. Section 4 Project overview will discuss project methodology and approach from design to implementation. Section 5 BushfireAR development will give a detail look on thesis production process. Section 6 Results will present collected data form playtest sessions. The thesis will then conclude in Section 7 by identifying the limitations associated with this project and the potential future work.

Section 2: Project Motivation

With the requirements listed above, this project will conduct research on simulation design first and foremost. Understanding the nature of bushfire is very important to provide an appropriate simulation. Namely: lethality, spread speed, the amount of effort required to extinguish, objects that are vulnerable to fire, and the effect of topology on fire. The project aims to provide simulated scenarios that resemble real bushfire incidents. Therefore, the project has devoted significant time and effort in designing the simulation scenario as serious game levels. This includes collecting, analysing and simplifying real world data.

Secondly, the project will focus on an Augmented Reality (AR) experience. AR devices, development tools, and function are seeing an increase in interest across many sectors, and provide a new way of presenting interactive, immersive experiences. Thus, the project will explore and utilise the advantages of AR in designing the user experience.

Finally, the project will explore the usefulness of the simulation. Based on the feedback and playtest responses to balance and enhance the experience. This pilot evaluation will consider the application of the project in a training and education context.

Section 3: Literature Review

This section includes reviews of literature in the three fields of: bushfire response, Serious Games (SG), and Handheld Augmented Reality (HAR). Those themes are the main building blocks for the understanding of the proposed research project. This literature review is structured with three main sections. The first section (3.1) gives an overview of the bushfire crisis in Australia and methods for raising the awareness of bushfire preparedness. A review of the relevant games and simulation systems that tackle emergency response issues follows. The second section (3.2) then discusses the definition and applications of SGs, focusing on SGs for the purpose of Education. The section then reviews principles and methods to construct an SG. The third section (3.3) discusses the literature around Augmented Reality (AR), then focuses on HAR in Collaboration. Following this, an analysis of framework for evaluating AR in mobile applications and its usability is presented. The final section (3.4) summarises this chapter, comparing and illustrating the impacts of those studies on this research project.

3.1. Bushfire and Response

3.1.1. Bushfire in Australia

In attempting to develop an application to help educate and inform Australians about the issues and dangers associated with bushfires, it is important to understand what defines a bushfire and the types of response systems that have been put in place. This section will first outline some of the features of bushfires in Australia, then look at the bushfire response employed in Australia, and finally comment on the education practices involved in raising bushfire preparedness and awareness.

Bushfires and grassfires often start as small fires, then due to many factors, this small ember can ignite surrounding fuel and become massive and unstoppable. It can cause severe damage to people, industry, housing and the environment. Even though it is highly destructive, bushfires are one of the building blocks of Australian ecosystems (Bradstock, 2012). The bushfire incidents that have happened every year, for a million years, have changed the ecosystem of Australia: plants and animals had to evolve to survive the fire, the ashes enrichened the soil, and the growing of the new generation of trees changed the forest distribution and landscapes (Bradstock, 2012).

According to Geoscience (2020), the ignition source of bushfires may vary from both human activities and natural causes with lightning accounted for half of the bushfires in Australia. Bushfire from human activities are taken seriously in Australia, and the penalty can be up to life imprisonment in some states (Lansdell, Anderson, & King, 2011). Australian weather is mostly hot and dry, creating vulnerabilities in the bush to bushfire, especially in summer and autumn. The places that are most likely to be the origin of bushfires are primarily dry grassland and Eucalypt forests (Geoscience, 2020). Given the devastation that these types of natural disasters can cause, it seems prudent to investigate how the Australian public can be educated through accessible strategies to the dangers associated with bushfire.

Fires often start small, but due to both natural and artificial reasons, the fire can escalate fast. Many aspects affect the channelling of the fire, but these are the basic factors: ambient temperature, fuel load and moisture, wind speed and slope angle (Geoscience, 2020). Fuel load is the burning material near the fire; it could be leaves, branches, bark, dry grass, houses, and other flammable materials.

> *"The greater the fuel load, the hotter and more intense the fire. Fuel which is concentrated but loosely compacted will burn faster than heavily compacted or scattered fuel sources. Smaller pieces of fuel such as twigs, leaf litter and branches burn quickly, particularly when they are dry and loosely arranged and will burn quickly in the fire front. Larger fuels, such as tree trunks often burn later after the fire front has passed. The natural oil within eucalypt trees promotes the combustion of fuel"* (Geoscience, 2020).

About fuel moisture, it is obvious that the high dryness of the fuel will create ideal burning material. The next factor is wind speed. Geoscience (2020) published that "wind acts to drive a fire by blowing the flames into fresh fuel, bringing it to ignition point and providing a continuous supply of oxygen. Wind also promotes the rapid spread of fire by spotting, which is the ignition of new fires by burning embers lofted into the air by wind. Spotting can occur up to 30km downwind from the fire front". And due to the nature of the fire, the upward slope will help the fire to spread uphill (Geoscience, 2020). When considering the development of a simulated interactive environment it is important to understand how such real-world systems behave. With this understanding of bushfire ignition and propagation, the system should be able to implement models to simulate the realistic spread of bushfires within the simulated environment.

Even though bushfire plays an essential role in the Australian ecosystem (Sharples et al., 2016), its damage is a real cost to Australia and has been escalating at an alarming rate. Bushfires have been a severe problem in Australia in recent years. Every year, the bushfire crisis leaves devastating damage to the environment, people, animals, and infrastructures. From 1901 – 2011, 260 bushfires were linked to 825 known fatalities, and thousands of houses burnt and destroyed (Blanchi et al., 2014). In 2009, the Black Saturday was recorded as one of the worst bushfire events with 168 fatalities and 2,021 houses lost (Blanchi et al., 2014) with an estimation of $4.4 billion economic impact in a single day (Sharples et al., 2016). In a report in 2016, the total economic cost of natural disasters in Australia exceeded $9 billion in 2015. If no further practical actions are taken, the economic loss from floods, storms, and bushfire to Australia could reach AUD$33 billion per year by 2050 (Deloitte, 2016). The estimation for the 2019/20 fire season was that 18.6m hectares had burned (Brooker, 2020), 3000 homes had been destroyed, human casualties were at least 28, while wildlife casualties were at least 30,000 dead koalas, out of approximately a billion animals in total, and serious smoke haze was recorded as bushfire damage in mid-January (McDougall, 2020). It has been confirmed that the 2019-20 bushfires were the worst in history, and 2019 was the hottest year recorded (McDougall, 2020). From those recorded figures, it is evident that the bushfire crisis in Australia is getting worse, and its effects are harder to predict year after year. The risk implicates actions from everyone to mitigate the impacts of bushfire in the coming years. This suggests a strong motivation for education and wider awareness about bushfires and the devastation they can cause. As such an interactive, game-based, handheld augmented reality experience could provide the sort of tool that educators and government could use to raise this awareness.

3.1.2. Bushfire response

In the case of a bushfire incident, various firefighting units (volunteer and professional) would be deployed immediately to extinguish the fire and deal with problems that are caused by the bushfire such as evacuate and rescue, animal rescue, fire risk control, and hazmat. In 2016/17, Fire and Rescue New South Wales (FR NSW) handled 6,537 bush and grass fires, and conducted 34 prescribed hazard reduction burns to reduce the fire risk for 991 properties (FRNSW, 2020). Beside the official firefighter force of the government located in major cities, bushfires in Australia are mostly handled by volunteers in remote areas. While the FR NSW has 7,000 paid firefighters with 335 fire stations, the volunteer-run NSW Rural Fire Service (NSW RFS) has 900 paid staff and 70,000 volunteers (SBS, 2019). FR NSW only handles incidents in the metropolitan part of NSW, while NSW RFS handles 95 per cent of NSW. Similarly, South Australia (SA) Country Fire Service (SA CFS) handles most of the bushfire and fire incidents in SA, around 7000 incidents each year. SA CFS has around 434 brigades across SA, more than 13,000 volunteers (sa.gov, 2020). Even though most of Firefighters are volunteers, they undergo strict official training, they are provided with legal protection and standardised equipment (SBS, 2019). According to the Victoria Country Fire Authority (CFA), all volunteers will have to take compulsory, minimum skill training for up to six months (CFA, 2020b). After the training, volunteer personnel will have to live or work close enough to their brigade to get there within a timely period in case of an incident (CFA, 2020b). The equipment is varied between brigades, but they are sufficient and suit the needs of each area. All fire stations have a training area, workshop, amenities, and vehicle bay hosting 2 or more emergency vehicles (CFA, 2020a). According to CFA and CFS, there are many types of fire appliances, some notable vehicles used in fighting bushfires are:

- Fire trucks, Tankers, Pumpers (Figure 1): The typical firefighter vehicles that are basically trucks carrying a water tank with equipped pump. They are also equipped with an extensive inventory of ladders, nozzles, hoses, suits, first aid kits, ropes, Trauma Teddys (stuffed bear toy that help to comfort children), and other emergency supplies. These vehicles are of various sizes in order to provide choice and strategic priority when dealing with different circumstances. The biggest vehicle can hold up to 4,000L of water in its tank.

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Figure 1 – Fire trucks (CFS, 2020; FireRescueNSW, 2020).

- Air Support vehicles (Figure 2): In the fire season, air support may be utilised for fast deployment. The aeroplanes often carry foam or water bombing technology and release at the needed places. But the aeroplane also requires fast refilling. Therefore, it is often accompanied by a tanker.
- Quick Response Vehicles (Figure 3): In some rural areas, due to steep landscape or narrow roads, it is impossible for normal vehicles to approach. A smaller firefighter vehicle, around the size of a pickup truck is used instead. This vehicle carries a 500L tank and basic equipment.
- Robots and new vehicles (Figure 4): Recent years, several special additional vehicles have been introduced. Special vehicles such as snow mobility unit or surveying drone was introduced to

aid bushfire fighting. In 2017, NSW introduced the remote-controlled robot TAF 20. "The TAF 20 (Turbine Aided Firefighting) machine can move cars out of the way with its bulldozer blade, clear smoke from a building with a high-powered fan, as well as spray water mist or foam for 60-metres and blast water for 90-metres" (Emergency.NSW, 2015).

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Figure 2 - Air support vehicles (CFS, 2020).

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Figure 3 - Quick Response Vehicles (CFANews, 2020).

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Figure 4 - New vehicles for firefighting (CFANews, 2020; FireRescueNSW, 2020).

Beside Firefighter organisations, Police and Medical services also have their own responsibilities in handling bushfire incidents. The coordination between them is critical for the effectiveness in resolving any emergency situations. Tasks for the police include: escorting other vehicles, building roadblocks, evacuations, and traffic management (Parliament.VIC, 2009). For the medical services, their responsibilities include: dispatching paramedics, ambulances, air ambulances, as well as on site emergency care and coordination.

The intention with the simulated, augmented reality environment to be built for this project was to incorporate as many real-world systems and artefacts into the experience. Understanding the role, capacity and functionality of these real-world items is essential to represent them in a convincing and believable way.

3.1.3. Raising Bushfire awareness

As an essential part of handling bushfires, the Australian government has taken many actions to raise Bushfire awareness. Beside official detailed information on related government websites, all firefighting organisations also issue informative materials through different means of media.

The CFA website has a dedicated tab for Schools (CFASchools, 2020b). Targeting young adult and child audiences, CFA provides comprehensive leaflets, informative lessons, survival guides, and game templates. Besides puzzles and simple colouring games to attract children attention, there is a game called Home Defence (CFASchools, 2020a). The game introduced a simple game where players can place houses, trees, and flames as level setup. The players then rotate a spinner to get a wind direction that will cause the fire to spread. The players will have to place the firefighters and vehicles to put out the fire. This game gives information about both bushfire and responses. CFA also embraces the power of interactive websites to provide a better observation of how fires spread and the fire danger rating. They also established a learning centre with a Safety Village empowered by physical activities and interactive multimedia facilities.

Utilising this approach as a starting point it was seen that the types of learning activities and information could be provided in a system that promotes engagement, interaction and immersion. Through an augmented reality, multi-person, multi-presence application teams of students, and other interested parties, could help plan a response and understand the devastation and complexity of managing these types of natural disasters.

3.2. Serious Games

3.2.1. Edutainment and Serious Games

Video games, computer games, or games, in general, are often referred to as entertainment products. However, since the first development of games, they have been used for more than purely entertainment purposes. Games like Go, Chess, and Senet were all used for a range of purposes from religious mysticism, through to honing strategy and planning, the Olympics were set up originally as a mechanism for demonstrating military prowess and training, and games like Monopoly were originally based on the game Landlord's Game which sought to demonstrate the dangers of capitalist approaches to property ownership, taxes and renting (Wilkinson, 2016). But in recent decades, with the introduction of digital games, there has been a trend that has emerged and transformed games to explicitly target and facilitate teaching and learning. Those trends brought more meaningful values to games by embodying knowledge and simulating real scenarios, thus teaching in a more intuitive way compared to conventional methods. Those trends include Edutainment and Serious Games. Unlike Edutainment, which is the fusion of original education activity with several game mechanics, Serious Games (SG) is still a game at its core. And it is developed not just for entertainment purposes but also for nonentertainment purposes such as education, business, social change and health care (Charsky, 2010).

The idea of edutainment or games in education is not new. Tansey (1969), in his book, discussed the use of games and simulations for education purposes. The early adaptations of edutainment were primitive and mostly in the form of physical activities and pen and paper-based play. Charsky (2010) mentions that from the 70s to 90s, "Edutainment and instructional computer games were once touted as the savior of education because of their ability to simultaneously entertain and educate" but "have received a terrible reputation for being the worst type of education, drill and practice activities masked with less than entertaining game play" due to the limitation of technology as well as methodology. Edutainment emphasises instructional information and attempts to motivate players with game-like features (Michael J. Hannafin, 1988). With the development of technology in recent years, computer systems have more processing and graphical power than they did in the past. New systems empower better graphics, audio, and computational strength that could not be realised even a short five years ago. This continuous evolution in technology directly improves the quality of computer applications and games. "Real-time computer graphics can achieve near-photorealism and virtual game worlds are usually populated with considerable amounts of high-quality content, creating a rich user experience" (Ma, Oikonomou, & Jain, 2011). Thus, there was a shift in the direction of the design and implementation of edutainment. To utilise the superior power of computers, edutainment started to be more computer-based and virtual. This shift motivates the trend of modern SGs. "The pervasiveness of gaming, the widespread use of the internet and the need to create more engaging educational practices have led to the emergence of serious games as a new form for education and training" (Ma et al., 2011).

The term serious game was defined in 1970 by Abt (1970). In his book, the definition of serious game is not different from edutainment mentioned in the book of Tansey (1969). With the computer evolution, the definition of SG changed. Zyda (2005) defines SG as "a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives". It is clear that there is a broadening in purposes in SG definition. Marsh (2011) in his article about "Serious game continuum", gives a formal definition for SGs as:

> *"digital games, simulations, virtual environments and mixed reality/media that provide opportunities to engage in activities through responsive narrative/story, gameplay or encounters to inform, influence, for well-being, and/or experience to convey meaning. The quality or success of serious games is characterised by the degree to which purpose has been fulfilled. Serious games are identified along a continuum from games for purpose at one end, through to experiential environments with minimal or no gaming characteristics for experience at the other end".*

In this research, SG will be referred to with its modern definition: A serious game is a game that not only carries entertaining values, but also serves a serious purpose such as knowledge transfer, personal expression, simulation, marketing and social change and can be effectively used in education, emergency management, training and preparation (Charsky, 2010; Girard, Ecalle, & Magnan, 2013; Ma et al., 2011; Marsh, 2011; Zyda, 2005).

3.2.2. Characteristics of a Serious game

SGs at their core, are still a game. Therefore SGs still consists of attributes and characteristics of a game. Charsky (2010) summarised five main characteristics of SGs as below:

- Competition and Goal: This defines the win condition of the game. It could be either set as a fixed goal or through competition with other players or the system. This motivates the players to play and finish the game.
- Rule: This defines constraints and limits for the player's actions. This is the tool for the game designer to shape the game with predetermined actions.
- Choice: Choices give players freedom (under the given Rules) and helps players to achieve the Goal. In SGs, Rule and Choice serve as important elements of information transmission.
- Challenge: Challenges are tasks and activities that the player must overcome in order to achieve the game's Goal. In SGs, the expected learning outcome should be designed as Challenges and integrated seamlessly into the game.
- Fantasy: Fantasy helps to boost the attractiveness of the game. In SGs, fantasy elements "assist learners in recognising the relevance and complexity of content while facilitating their ability to transfer and generalise their understanding to the real world".

While game characteristics are the guiding elements, game attributes are the detailed implementation that shapes gameplay. Lameras et al. (2017) proposed a classified table (Table 1) that maps SG characteristics with Game attributes.

Table 1 - Game categories and associated game attributes by Lameras et al. (2017).

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3.2.3. Games with Emergency management and Response theme

Due to their attractiveness and the relevance that games have with emergency themes such as Police, Firefighter, and Medical services, there have been several games created for these types of experiences. They ranged from well-known board games such as Hotshots to video games like 911 Operator and Zero Hour. As those games have a similar purpose of simulating emergency management and response theme into gameplay with the project presented in this thesis, a short review of each game will be discussed to understand the implementation of such purpose.

Hotshots is a board game designed by Justin De Witt (FireSideGames, 2017). In the game, 1-4 players will play together cooperatively to extinguish wildfires on a tiled area. The map is divided into tiles, and each tile has several characteristics, namely type of place, flammable level, required tools to control fire, and provided tools to complete special actions. At the start of the game, there will be several fires on the board. Players can move a certain number of steps around the map each turn. Then each player has unique skills and tools determined by dice rolling. When those provided skills and tools match the tile they have moved to, they could extinguish the fire. As a board game, the game focuses on special interaction between character and tile as well as dice rolling mechanic. Successfully extinguish the fire will stop it from expanding to adjacent tiles. The game creates interesting gameplay with wildfire as the main theme. Images captured of gameplay for Hotshots can be seen in Appendix A.

911 Operator is a commercial game by JutsuGames that simulates the work of a 911 call handler and an emergency responder manager (JutsuGames, 2020). In the game, the player will have the ability to manage responder team vehicles and their placement on a large map at the scale of a city, and team personnel with equipment at the start of the day. Then throughout the day, there will be a series of incidents reported through 911 calls or from the report system. The gameplay focuses on managing resources on the map as the vehicles number and capability are varied and limited while there is a time pressure, and protocol to respond and react to a 911 call properly which can sometimes be tricky (JutsuGames, 2020). At the conclusion of the day, the player will be rewarded for their timely responses and advised of what they did wrong in certain cases. The game successfully simulates the difficult work of emergency responders, yet not too serious gameplay, making it an entertaining video game with unique gameplay. Screenshots of the game can be found in Appendix A.

Zero Hour: America's Medic (ZH) is a game designed to train and exercise first responders in handling disaster incidents (UnrealEngine.Blog, 2008). The game was created by Virtual Heroes, a leading SGs developer with many successful SGs specially designed for both professionals and normal practitioners in medical, education, military, and government applications (VirtualHeroes, 2020). The game focuses on realistic simulation and protocol needed in mass casualty disasters. Given the situation, the player as an Emergency Medical Services (EMS) personnel will have to handle a huge number of unique issues that resemble the real protocol and practices. When the session is over, the player will be given a detailed reporting about their performance. The game became one of the tools used in EMS recruiting process (VirtualHeroes, 2020). The feedback from players was positive. For professional personnel, the game helps to prepare them for a hard situation that rarely happened and never trained for. For regular players, the game helps to give more information about the challenges EMS workers are facing every day and the crucial information about how to act in the case of an emergency (UnrealEngine.Blog, 2008). Screenshots from Zero Hour: America's Medic have been included in Appendix A.

3.3. Handheld Augmented Reality

3.3.1. Augmented Reality

With the continual development and improvement of computational and display technology, the computer systems had gone from big mainframe systems with small black and white screens to palm-sized portable computers and huge monitors capable of displaying billions of colours (Peddie, 2013). As the increase in processing, graphics, tracking and portability of computers continues to grow, and this enables new opportunities. For both development and commercial purposes, researchers, as well as technology companies, continuously experiment with new and break-through human-computer interaction methodologies. Many experiments go beyond the conventional human-computer interface paradigm of utilising keyboards, mouses, and monitors. They introduce new visualisation technologies, enhanced by new interaction technologies. Extended Reality (XR) is one of those advances in technology. Technology companies like Apple, Facebook, Google, Microsoft, and Sony are heavily investing in XR in recent years for both consumer and business sectors (Fujiuchi & Riggie, 2019). The term XR refers to the technology that uses special audio-visual technologies to merge user and virtual content into a single complete experience. As the name suggested, XR extends reality beyond the physical boundary and break the user free from the limitation of conventional controller devices. In most XR experiences, user senses are augmented with rich content such as visual, audio, simulated surfaces, and in some situations even smells and taste. According to Fujiuchi and Riggie (2019), "Extended reality (XR) is an umbrella term that encompasses Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR) technologies". Milgram, Takemura, Utsumi, and Kishino (1995) in their paper to differentiate AR from VR proposed that AR and VR can be put into a Reality-Virtuality continuum (RV continuum) in Figure 5 below.

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Figure 5 - Simplified representation of RV Continuum (Milgram et al., 1995).

According to Milgram et al. (1995), on the left of the continuum is the environment that consists solely of real objects while on the right of the continuum is the environment that consists solely of computer-generated objects. AR is more on the left, VR is on the far right, and MR is used to define the blending of the virtual and the physical.

VR is the technology that immerses the user within a total computer-generated virtual environment. In this technology, users are presented with a simulated view which is removed from their physical surroundings through a Head Mound Display (HMD). By using close-proximity displays that directly illuminate user's eyes with computer-generated graphics, VR immerses its user to a totally virtual world (Dow et al., 2005; Milgram et al., 1995; Schnabel, Wang, Seichter, & Kvan, 2007). This technology has been developing fast over the last decade and starting to gain significant popularity with an interested consumer base.

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Figure 6 - Sutherland (1968) HMD system

While VR is the technology to replace the real world, AR, on the other hand, is the technology that augments the physical environment surrounding the user by adding virtual elements or removing real objects. Those elements can be perceived through a wide range of human senses, including sight, hearing, touch, smell, and taste (R. Azuma et al., 2001). Those virtual elements can enable the user to access additional information and thus can help them to achieve real-world enhancements (R. T. Azuma, 1997). Due to the constraint of time and effort, this project will focus on AR technology that utilises mobile device display technology. One of the first such AR systems was introduced in the 1960s by Sutherland (1968). This is a complex mechanical and computer system with a see-through HMD (Figure 6). The system displays a 3D object in the HMD. And when the user moves around, the computer will show that 3D object from an appropriate perspective. Thus, the user has the illusion of a virtual object in their real physical world (Sutherland, 1968). From then to the 1990s, AR and VR are often mixed by researchers. Some refer to AR as VR with a see-through HMD (R. T. Azuma, 1997). In 1995, Milgram et al. (1995) published a work that reviewed the term AR and introduced the RV continuum. This paper clearly differentiates AR from VR as well as laying the building blocks for the development of AR in the coming years. Since then, AR has been growing rapidly and gaining significant popularity (Sicaru, Ciocianu, & Boiangiu, 2017). Major technology companies have introduced many exciting AR solutions. Overcoming technology challenging roadblocks of AR including display, tracking, registration, and calibration has been considered one of the top goals by researchers and technology companies around the globe (R. Azuma et al., 2001; Chatzopoulos, Bermejo, Zhanpeng, & Pan, 2017). This increase in popularity is advancing AR faster than ever. Many new players such as Facebook, Apple, Magic Leap, Snap, and Unity are now investing in AR enabling hardware development as well as AR software systems.

AR has been proving its capabilities in a broad range of fields including medical, education, retail, training, engineering, and entertainment. Applied in those fields, in term of user experience, AR technology provides significant advances. The AR experience still allows users to see their surroundings, people and objects around them while showing synthetic elements in that surrounding (R. T. Azuma, 1997; Fujiuchi & Riggie, 2019; Milgram et al., 1995). In many cases, objects or concepts cannot be illustrated easily with the conventional graphical displays such as flat monitors. And many elements are impossible to have physically. In the medical field, they can be details of a simulated living human anatomy or display of internal organs of a patient; for education, those elements can be extinct animals, far-away planets; for retail, they can be products not present where the customer is located; and many others objects or situation where the physicality (real world object) is not a feasible option. These problems can be solved effectively with AR technology (Bork et al., 2019; Cai, Amrizal, Abe, & Suganuma, 2019; Fujiuchi & Riggie, 2019). Not only can AR systems display those elements in front of the user's eyes using computer-generated graphics, but the system can also anchor those elements in the real world through AR displays that make them almost physically present to the user's eyes (R. Azuma et al., 2001; Craig, 2013). This creates a unique experience where user can walk around their real-world while seeing augmented elements tied to their surrounding and interacting with them (R. Azuma et al., 2001; Chatzopoulos et al., 2017; Lackey & Chen, 2017). Therefore, AR is a useful, promising technology.

AR display technology can be classified as three main categories: Head-worn displays (HWD) or HMD in general, Handheld displays, and Projection displays (R. Azuma et al., 2001). AR HMD group contains some of the most break-through technology such as lightweight yet high-density optical display or low-power laser that can draw directly on the human retina. Newly introduced see-through HMD system Microsoft Hololens 2 let the user see 3D augmented objects in their surrounding at a resolution of 2K while only weighing 566g (Microsoft, 2020). This system also packs eight cameras and advanced technology sensors to track the presence and volume of real-world objects and user movements (Microsoft, 2020). With heavy investment from companies, this category will continue to evolve in the future. The second category is Handheld displays. This category includes systems that are utilising a portable display, computer, and camera. In this group, mobile phones are the most significant member. In the past, AR displays relied on a big monitor showing real-world video and augmented elements together. Mobile phone with its small display and strong computational capability solved the problem of the last generation big AR displays (R. Azuma et al., 2001; Hedberg, Nouri, Hansen, & Rahmani, 2018; Milgram et al., 1995). The last group is Projection displays. In short, systems in this category often project virtual elements directly onto the real objects using projectors. This approach helps to achieve AR experiences without the need of a worn or held devices (R. Azuma et al., 2001).

3.3.2. Handheld AR

Handheld AR (HAR) is developing fast, along with the development of mobile phones and tablets in the last decade. The power of new generations of smartphone and tablet has been showing an exponential increase in computation strength, thus enabling more complex applications. Two major mobile phone operating systems, iOS and Android, along with many others software providers such as Vuforia, Unity, and Unreal Engine, are all pushing for AR as one of their primary applications, creating a new era of AR. Mobile phones and tablets are now more powerful than ever. They are not just simple devices for making phone calls but also a small handheld powerhouse that packs powerful processors, multiple high-quality cameras, and complicated sensor systems. The combination of the software and hardware enable high-quality AR on mobile phones and tablets (Chatzopoulos et al., 2017; Haynes, Hehl-Lange, & Lange, 2018; Hedberg et al., 2018). HAR is a member of the bigger group Mobile AR (MAR). MAR is all the AR systems that are portable such as mobile phones or portable HWD. According to Chatzopoulos et al. (2017), three characteristics of a MAR system are:

- Input: The system collects data from cameras, accelerometer, compass, GPS, gyroscope sensors, and other sensors.
- Processing: Remotely or locally, the device processes the input and determines what to render.
- Output: The device displays the output to the screen overlaying the current camera view.

AR on mobile device experiences not only have the portability of the mobile phone or tablet but also the computing technology to power AR. Thus, in the last few years, there has been a massive trend of HAR mobile applications in most areas such as education, tourism, culture, and especially games (Sicaru et al., 2017). Those applications have been gaining substantial success in popularity and financial earnings (Chatzopoulos et al., 2017). According to ARInsider (2020), there were 334 million active AR users in 2019, and this number will grow to more than 1 billion by 2023. As mobile phones become important personal devices and tablets become popular equipment for study and entertainment, MAR offers a low barrier of entry to the user yet brings an exciting experience. With those advantages, mobile devices are the ideal platform for the application designed as part of this project.

3.3.3. Mobile AR frameworks

Since the characteristics of a mobile phone such as the high-resolution display, equipped camera, complex computational capabilities, motion tracking, and portability, mobile phones are one of the most suitable platforms for AR. Not only are mobile phones in an ideal position to handle the complexity of HAR, but mobile phones can also open AR to a huge set of potential customers. Apple started pushing AR in their products line in 2017 and followed not long after by Google in their Android platform. The release of AR as part of default platform SDKs as well as significant promoting moves by Apple and Google resulted in a major increase in MAR applications (Apple, 2017; Google, 2020). Digi-Capital noted that the AR market had an approximately 900 million active install base and more than US$8 billion revenue in 2019 (Digi-Capital, 2020).

Major MAR technologies such as ARKit (AppleARKit, 2020) and ARCore (GoogleARCore, 2020) utilise Simultaneous Localization And Mapping (SLAM) systems. Those systems use computer vision on the camera feed to detect features and anchors, combined with the motion of the phone to provide a comprehensive AR experience (Figure 7).

Image removed due to copyright restriction

Figure 7 - ARKit Behind the scenes. Motion data and Computer vision (Apple, 2018).

Even though MAR is developing fast, there are still major limitations in MAR applications. One of those problems is, due to the small form factor, the inability to run intensive applications for a long duration. When the CPU and GPU of the mobile phone are requested to handle complex applications, they have to activate all of their cores, thus consumes more battery, and eventually produces significant heat. To protect the phone from heating up to a dangerous level, after a short duration of managing intensive tasks, CPU and GPU will be throttled. This action directly affects the performance of the running application. In the case of the video game, complex computational tasks happen every frame (Unity3D, 2020c). The reduction of CPU and GPU strength will result in a longer time required to finish a task. This potentially reduces the framerate of the video game. In some cases, this can cause a mismatch of AR display and real-world. Those performance problems eventually reduce the quality of the video gameplay session. Users may decide to end the game as it gets laggy (Hu & Zhu, 2014). This implies that it is crucial to optimise computational tasks in the proposed product to maximise its playtime, maintain good performance, thus, ensure its delivery of information.

3.3.4. AR Collaborating

According to Billinghurst and Kato (2002), the surrounding physical world and objects play an essential role in collaboration tasks when communicating face-to-face. Real object features such as appearance, size, and weight can help participants to recognise and relate to the scene, thus enabling better communication. AR technology, with its characteristic of retaining the awareness of the user to their surroundings, not only keeps that real objects presence advantage if used in face-to-face communication, but also provides the capability of displaying virtual 3D objects to improve participants' shared understanding (Billinghurst & Kato, 2002). Szalavári, Schmalstieg, Fuhrmann, and Gervautz (1998) proposed that a collaboration AR system should have fundamental properties as below:

- Virtuality: Allowing users to view and examine virtual objects.
- Augmentation: Real-world objects can be augmented with virtual information.
- Multi-user support: Multiple participants can attend and communicate naturally with each other.
- Independence: Users can move their viewpoint by physically moving as they want.
- Sharing vs. Individuality: What participants can see can be the same or different based on their needs.

AR can help to create a seamless collaboration where physical objects, virtual objects, and interactions are all important equally (Billinghurst & Kato, 2002). HAR systems have the portability of handheld devices thus offer great capabilities supporting the aforementioned fundamental properties. Utilising the power of AR, it is clear that the proposed system can promote meaningful collaboration for multiple parties and achieve the expected educational effect.

3.3.5. AR Usability Scale

It is important for every HAR applications to collect user feedback, especially when AR is developing fast and pushing greater experimental potential than ever (Chatzopoulos et al., 2017; Santos et al., 2014). Therefore, Santos et al. (2014) proposed the HAR Usability Scale (HARUS). Usability is how easy to use the application. To address usability, HARUS has 16 statements that ask for the user's feedback. Those problems are categorised into two main groups: Perceptual issues and Ergonomic issues. Perceptual issues include problems such as limited visibility, object registration, high latency, and feedback problems. Ergonomic issues include problems that come from devices physical characteristics such as weight, size, screen reflectiveness, and feedback time (Santos et al., 2014). Each statement in HARUS can be connected directly into the HAR system one or more issues as described in Table 2. Based on results from participants responding to the HARUS, one can determine the problems of a HAR system and the origin of those issues (Santos et al., 2014). With that information, the HAR developers can adjust and make appropriate changes toward a better application. Therefore, HARUS is a great tool for measuring the usability of HAR applications.

Table 2 - The HARUS by Santos et al. (2014).

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3.4. Summary

In this chapter, a summary of research about bushfires, serious games, and handheld Augmented Reality related to this project was discussed. Bushfire damage in Australia is severe, and efforts to raise awareness about it is needed more than ever. Serious games are a special type of medium that serves both entertainment purposes and serious purposes. And finally, handheld Augmented Reality is a platform that has the ability to blend the real world with the virtual world through mobile phone displays. Reviewing the literature discussed above has set the starting point for this study.

Section 4: Project overview

4.1. Project objectives

The main objective of this project was to contribute to the design and development of a novel serious game that helps to raise the awareness of bushfires and bushfire responses. The prototype version focused on demonstrating the impact of bushfire on natural vegetation and human infrastructure and simulating the tasks of bushfire responders in planning and action. The game aimed to educate the players about the damage of bushfire and the hardship of bushfire response forces through an interesting approach of a playful, AR serious game. The target audience for this game was young adolescents between the ages of 10-14.

4.2. Methodology

In this project, a pilot study was conducted to confirm suitability, usability, functionality of the proposed serious game for the target audience. The study was backed by a limited evaluation. Project production was divided into two phases. In the first phase, a novel serious game prototype was developed presenting the main inspiration topics of bushfire and bushfire responses. Prototypes were tested internally by developer, supervisor and friends to collect data on aesthetic direction, performance, game features, and interaction design. In the second phase, the developed prototype was evaluated in a small limited group. Testing and evaluation data then was collected and analysed. The final results implied the potential of the future development of a completed serious game with testing in a large group. Further discussion about the design and development of the AR application is presented in Section 5.

4.3. Research design

The product of the project is a SG named BushfireAR. To reduce the complexity of game development, BushfireAR was developed in Unity, a cross-platform game engine. BushfireAR targeted general and young audiences and on both major mobile platforms of iOS and Android. BushfireAR covered five bushfire scenarios to gradually lead players through learning gameplay mechanic tutorial to solving bushfire incidents. The game operated on mobile devices of participants or provided test devices. Internal BushfireAR testing sessions were conducted by the distribution of Android executable files. If the participant could not test the game on Android, an iOS device with the game installed was provided. The development and evaluation will be discussed in detail in Section 5 – BushfireAR development and Section 6 – Results.

4.4. Survey design

The developed survey focused on four main parts: demographic information, bushfire awareness before the participant plays the game, HARUS (Santos et al., 2014), and impact on bushfire awareness after the participant plays the game. The demographic information section covers generic details about participant's age, gender, mobile device, their familiar with games, AR, and HAR. The bushfire awareness section designed to collect data about participants' information regarding bushfire damage in Australia season 2019-2020. Since BushfireAR is a HAR application, the HARUS was then added to the post experiment survey to identify the quality of AR user experience (UX) design. The HARUS contains 16 questions that are rated on a seven point scale from Strongly Disagree to Strongly Agree, design outcomes are validated in terms of:

- Ergonomic: how comfortable the participant is while playing the game.
- Usability: how easy to understand, interact, and operate BushfireAR.

The final section of the survey conveyed how the play session affected the users' perspective on bushfires and bushfire responses. This section was designed to verify the effectiveness of the developed SG in raising participants' awareness in bushfire and bushfire responses.

Section 5: BushfireAR development

5.1. Feasibility study

Main features of BushfireAR were drafted at the start of the project production phase. Based on the project objectives discussed in 4.1., those main features are:

- The game is able to simulate bushfire and bushfire responses.
- The game is able to run on mobile devices.
- The game is able to provide an AR display and interaction.

Those features then translated into three main technical features:

- It is an interactive game.
- The game world is in a 3D environment.
- It is capable of displaying in AR environment on iOS and Android mobile phones.

Several separate independent prototypes were developed to verify the feasibility of the final software product by confirming the ability to satisfy the three features above. Initial feasibility tests were conducted to determine AR interactions and presentation to the player, the game [AR]achnophobia was created to evaluate this (see Appendix B). For BushfireAR the first item to be experimented on was the game engine. Defold, XNA, Unreal Engine, and Unity were among the considerations. Each of those engines has its own strengths and weaknesses. But Defold and XNA were removed from the shortlist because they were not mobile-friendly at the project development time. Considering the project timeline and existing development experience, Unity (version 2020.1.8f1) was chosen over Unreal Engine. An AR prototype was developed to confirm the suitability of Unity (Figure 8). This prototype confirmed the abilities of Unity to detect horizontal and vertical planes (black outlined and yellow-coloured planes) by processing feature points (yellow-coloured dots) from mobile phone camera video feed. Virtual game objects then can be placed on top of those detected planes. The prototype demonstrated the ability to develop and deploy an AR game on mobile devices and provided a base functionality for highlighting detected objects as well as interacting with them within a scene (see Appendix B).

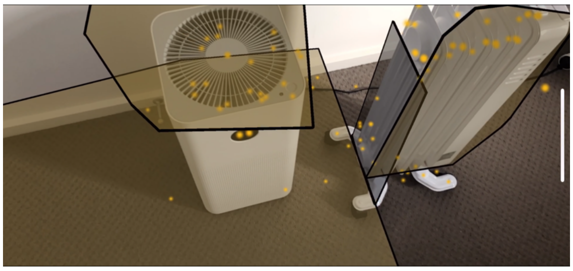

Figure 8 - Unity AR prototype running on iPhoneX

5.2. Development challenges

The final product was a novel serious game developed from scratch. Therefore, the project is a combination of the art design, game design, and software development. The difficulty in implementation of the dynamic of game elements, combined with the lack of experience in art design and game design pushed the project production phase longer than initially planned at the start of the project. To advance in game design and art design, shorter and smaller iterations were utilised. As a result, serious game development was divided into four iterations. The first two iterations focused on finding the appropriate aesthetic design and game design. The third iteration developed a set of ready-to-use tools to aid level designing tasks. The final iteration focused on building the scenarios and embedding narrative elements into the final game prototype.

In the first two iterations, the production of game assets was the most challenging task. In order to create a game with aesthetic integrity, the art direction must be clear at the start of the production. But due to the limitation of time and effort, high-fidelity game assets that resemble the real-world references could not be created. At this time, the question of how realistic the visual of the game should be also needed to be answered. Realistic 3D models of trees, houses, vehicles would not only require a professional game artist to create but also indirectly increase the complexity in how realistic the simulation is. Over simplified versions of them, on the other hand, can potentially reduce the authenticity of the simulation. During the iteration, several art directions were examined, sample assets were tested in game scenes, and major decisions were made to reduce the complexity of asset production tasks, thereby indirectly lowering the simulation expectation, thus balance the workload in both assets preparation and software programming. Those decisions will be discussed in detail in section 5.3 BushfireAR game design. In the latter two iterations, the most challenging task was to ensure smooth game performance and producing the least heat possible on smartphone devices. Even though smartphones are capable of displaying and computing more than ever (Hedberg et al., 2018), it is not easy for such small devices to maintain the best possible experiences for a long duration. When the phone has to compute and display complicated software such as games, it requires all of its computational capability, thus heats up (Hu & Zhu, 2014). The heat produced then prevents the phone's CPU and GPU from performing at their best. As a result, the CPU and GPU will be throttled to prevent heating up, thus reducing the performance of the graphical application dramatically. This behaviour has a direct impact on intensive graphical applications which the AR application is an example of. When the performance drops, frames per second will be reduced, game input will be unresponsive, and the application may lose AR tracking with their designated real-world anchors (Apple, 2018). Those deteriorations must be considered seriously and prevented from the start of the project to ensure an intuitive UI, a high-quality UX, and a sufficient gameplay session. Section 5.4. Implementation will discuss software solutions to address this requirement in detail.

5.3. BushfireAR game design

5.3.1. Game design overview

The primary purpose of the BushfireAR game is to raise awareness about bushfire and bushfire responses, the core game mechanics were designed around two main actions: burning and extinguishing. Game design was undertaken following five main characteristics of SGs by Charsky (2010). With each of those characteristics, BushfireAR attributes were defined:

- Competition and Goal: Completely extinguish the bushfire in several scenarios.
- Rule: The player has the ability to control the fire truck. The fire truck can hold a fixed amount

of water and can use that water to put out bushfires. The truck needs to be refilled when it runs out of water. The fire truck has limited travel ability. Bushfire will start and spread around the map. Section 5.3.2. Interaction Design will discuss the translation of goal and rule to game mechanic in detail.

- Choice: Each bushfire scenario allows the player to determine their own strategy for dealing with the scenario.
- Challenge: Different bushfire scenarios designed based on different tree formations, burn speed, burn intensity, fire truck travel ability, animal saving requirements. Section 5.4.6. Player's Journey will discuss scenarios introduced to form choices and challenges of the game.
- Fantasy: The gameboard resembles a small town where the player is the director of the fire fighting force. There is a narrator who guides the player and gives useful instruction.

An iterative approach was undertaken to address five serious game characteristics. Each iteration helped to explore the game mechanic as well as its look and feel. At the end of each iteration, suitable game design decisions are kept and brought to the next iterations. The final version was a balanced combination of goal, rule, choice, challenge, and fantasy reflected in a carefully designed serious game.

5.3.2. Interaction design

Game mechanic was designed based on concept images and early sketches (Figure 9). In-game interactions were tested in several iterations along with game aesthetic and mechanic.

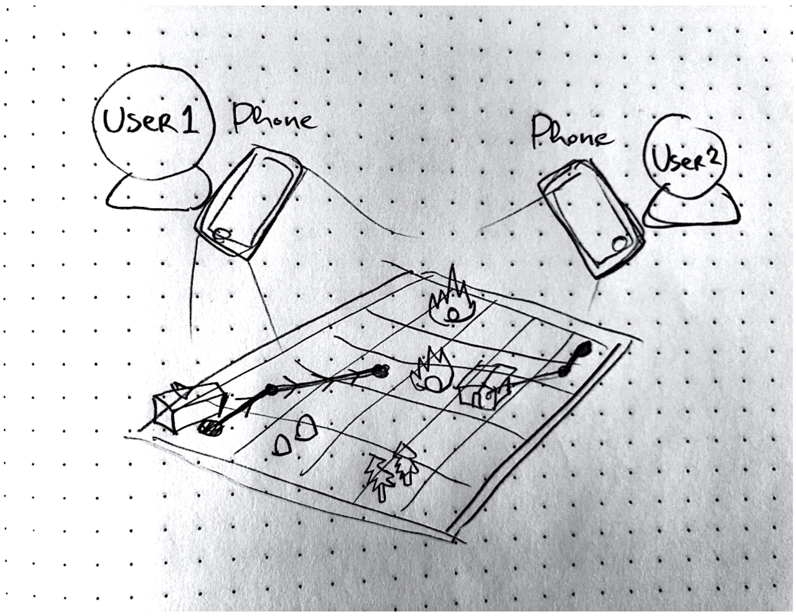

Figure 9 - Initial game interaction draft

To validate the game idea, physical prototypes were created to evaluate core game interactions. Since the expected system is an AR experience, a physical game board was gathered with toys, papers, and tissues (see Appendix C). A mobile phone with camera application running was used to emulate what the player would see with a MAR. Using this method, the concepts for main gameplay actions were defined. Technical prototypes then followed to test the actual game mechanic (see Appendix C). Those prototypes also helped to build the foundation of the game asset, code, and logic for the final BushfireAR system.

With the requirement in SG characteristics of goal and rule and ideas tested in prototypes, the final core game loop of BusfireAR can be summarised as Figure 10.

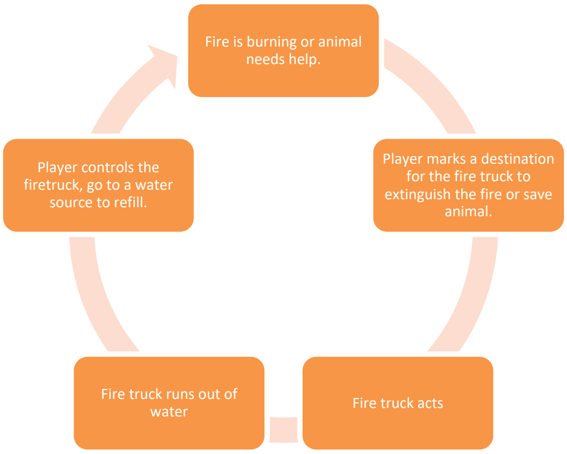

Figure 10 - Core game loop

The fire and its placement on the map, combined with the environment around it, forms the challenge. An in-game narrator, represented by a firefighter officer, will tell the player what action should be taken next. The player can touch the screen to mark a place to command the fire truck to move to. The narrator then reports back at the end of the game to show the player's performance. Those defined items formed core BushfireAR game mechanics.

5.3.3. Aesthetic design and assets preparation

One of the most challenging tasks in the design phase was to find a suitable look and feel. It was very important to have a clear style for the game. At the start of the project, early iteration utilised the idea of bringing a slice of the Earth to the game. Using the Blender GIS plugin (domlysz, 2020), by specifying an area on the map, a part of the real-world satellite map was imported into Unity to test the idea. The imported slice had a real satellite image as its texture combined with detailed height information to create a complete 3D model (Figure 11).

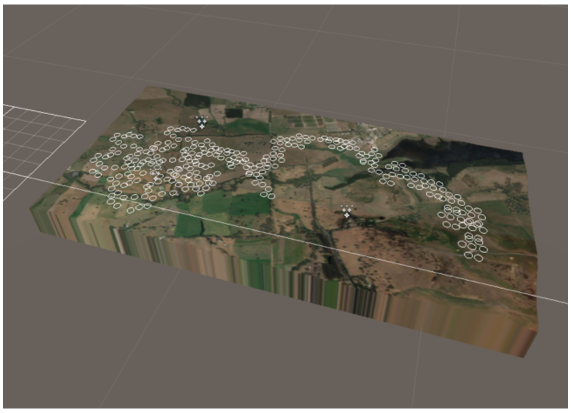

Figure 11 - Slice of Earth prototype

The problem that arose from this design was the complexity of the 3D game board model. This visual complexity would require the other game elements to be in reasonably high fidelity and realistic to match the game board style. Thus, this design dramatically increased the workload in asset preparation. Several iterations with different tree and game board style were tested to find a suitable look.

The final design was the combination of simple low-poly models with single vibrant colour texture placed on a flat map with modified Google satellite image. The style resembled plastic toys and board game tokens (Figure 12). This style had clear advantages compared to the realistic styles tested earlier in the design phase:

- The toy-ish look suited the target audience of the project. This choice made the game element more appealing to the children and young adults whose routines included playing with toys and board games.
- Low-poly style with plastic look reduce the complexity of model and textures. As a result, this choice also reduced the rendering burden of mobile phone CPU and GPU, thus, contributed to the optimisation requirement. This choice also made asset production less complicated.

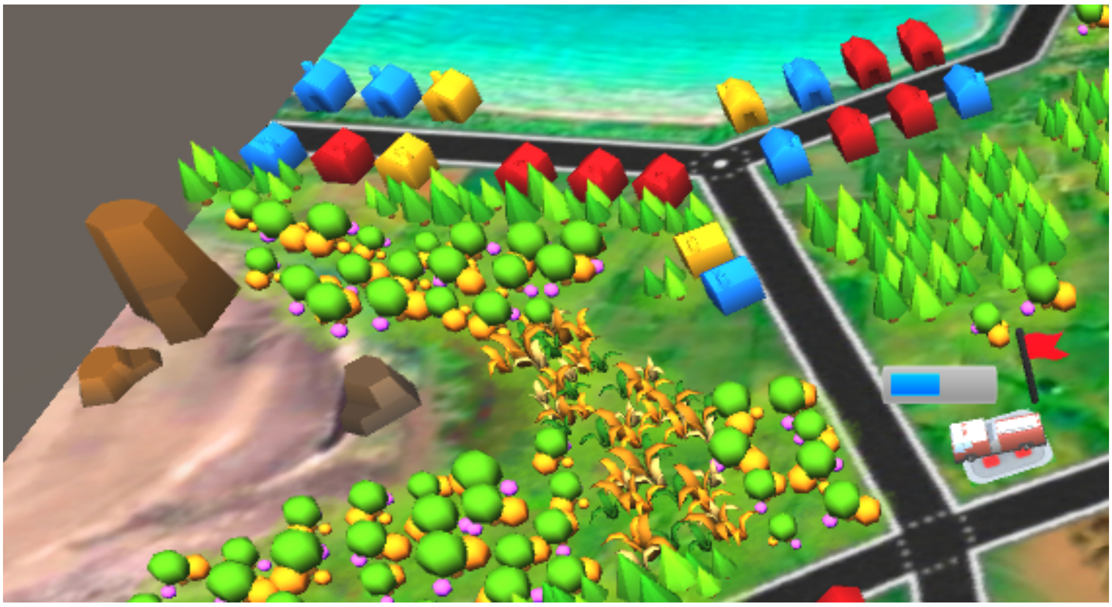

Figure 12 - In-game 3D models

A shader to simulate ambient occlusion was applied to achieve the gradient effect on 3D models with single colour texture. This shader helped to improve overall lighting without setting up complex and heavy lighting game objects.

Blender (Blender, 2020) was used to prepare in-game 3D models. Unity has the option to import Blender model files directly, which helped to cut down the preparation steps needed in importing assets. Photopea (Photopea, 2020) was used to prepare 2D in-game assets. Since asset creation is not my major, several models and assets were bought or free to use under CC3 license (https://creativecommons.org/licenses/by/3.0/). Fire truck and airplane are paid assets by cgtrader.com/NotBrown (2020). House model is free asset bycults3d.com/Reprappt (2020). Koala model is free asset bycults3d.com/Colorful3D (2020). Stone models are free asset by Craftpix.net (2020). Fire fighter narrator image is Apple emoji.

5.4. Implementation

5.4.1. System overview

BushfireAR was developed with purposes of not only providing an interesting AR serious game to the player but also preparing a comprehensive toolset in Unity editor for the game developer and level designer. The main components included:

- Main Game Controller: The global object that controls the game play related elements such as: fire propagation, water extinguish, and particles systems. Details of those elements will be discussed in details in next sub-sections. Main Game Controller plays an important role in game logic and state management.
- UI Controller: The global object that controls 2D UI elements such as narrator image, messages, and action buttons. This object also controls the final game over screen. UI Controller was implemented with set of ready-to-use functions, thus provided a comprehensive interface to Narrative Controller.
- Narrative Controller: The global object that handles game scenarios by directly controls Main Game Controller and UI Controller. Narrative related game objects are linked to Narrative Controller where they are manipulated to achieve the expected scenario.

The coordination of Main Game Controller, UI controller, and Narrative Controller provided a useful level builder toolset as well as a well-rounded game play experience (See Appendix C).

5.4.2. Bushfire simulation

The characteristic of fire is translated to game element parameters and was controlled by a script named **`Burnable`**. Those parameters included:

- **`IsBurning`** suggests whether the object is on fire or not.
- **`BurnRadius`** defines how far the fire can reach from current **`Burnable`** object.
- **`BurnRate`** defines how fast the fire increase in size and intensity by adding itself to **`CurrentBurn`**. Different type of tree has different **`BurnRate`** value. Grass and small bush have higher **`BurnRate`** compared to bigger tree and houses. Higher **`BurnRate`** means faster burning and spreading. In the case of animal, the **`BurnRate`** is very high as they cannot survive the fire. **`BurnRadius`** and **`BurnRate`** are designed to reflect the burn characteristics of fire fuels in real life.
- **`CurrentBurn`** defines the current burn state of the object as a float number from 0 to 1, when **`CurrentBurn`** reaches 1, the object is burned down. **`CurrentBurn`** value is also used to update the display object to trigger fire, smoke, and burnt down effect.
- **`Extinguished`** is the flag that suggests whether the object is extinguished or not. If an object is extinguished, it will not catch on fire again.

When two or more **`Burnable`** objects are put next to each other, the propagation decision between each pair which contains exactly one burning object is determined by comparing the coordinate distance between them with a sum of fire distances. Fire distance of an object is equal to its **`BurnRadius`** multiplied by its **`CurrentBurn`**. If the fire distance is larger than the coordinate distance, the burning object will ignite the not-burning one. This implementation simulated the propagation of bushfire in real life (Figure 13).

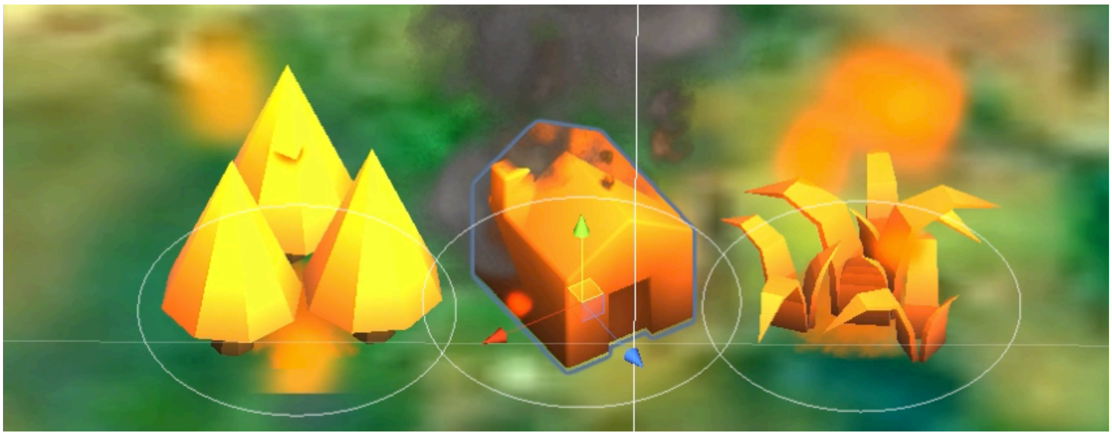

Figure 13 - Fire propagation

Beside those parameters working together to simulate the fire behaviours, another script called `BuranableDisplay` will take signals from `Burnable` to update object appearance. For example, if `Burnable` sends a signal about a fire started, `BurnableDisplay` will receive the call and update the 3D model accordingly by changing the texture to red and create fire particles. This approach enables polymorphism for `Burnable` object as the fire can start and spread not only on trees but also houses and animals. Thus, improve the scalability of the system.

Checking propagation condition is a complicated task. In normal Object-Oriented Programming approach, each `Burnable` object will have to find all other `Burnable` objects in the game scene, calculate the distance from itself to each of those found objects, and check if the burn distance is smaller than coordinate distance to determine the propagation decision. This task must happen every game render frame, which most of the time is 60 times per second. There are some key problems with this approach: Finding game objects by name is a heavy task that should not happen every frame and re-calculating the distance is unnecessary as `Burnable` objects coordinates are unchanged across the gameplay session. Understanding the heavy tasks of calculating and update every single `Burnable` object, the dynamic of `Burnable` was heavily optimised. The propagation logic was delegated to the main `GameController` where a list of `Burnable` is held. At the start of the game, all `Burnable` instances are appended to the list. From that list, an adjacency matrix of coordinate distances between any two `Burnable` was calculated. This matrix then plays as a reference distance map to determine the propagation condition between any two `Burnable` objects. Instead of calculating the propagation condition with every other object, `Burnable` only need to update the `CurrentBurn` value every frame in this approach. This coordination of `GameController` and `Burnable` dramatically reduce the number of calculations required on every frame. Thus, a smooth play experience is ensured.

5.4.3. Fire truck controller

The fire truck functionality was built with two main systems: the navigation system and extinguishing system. The navigation system was enabled through the Unity NavMesh and NavAgent systems. “NavMesh (short for Navigation Mesh) is a data structure which describes the walkable surfaces of the game world and allows to find a path from one walkable location to another in the game world”

(Unity3D, 2020b). In BushfireAR, by setting up the mesh for main roads and accessible areas in Unity editor, the NavMesh can be pre-calculated to a ready-to-use data structure. The game then only calculates based on baked data to complete navigation tasks instead of setting up complicated pathfinding algorithms on meshes. There are two types of travelable surface in BushfireAR (Figure 14): main road and accessible area. The fire truck can move very fast on main roads but slower on other accessible areas. The fire truck cannot travel to any area outside of those two types. This approach created a game-play dynamic as well as partly reflected the fact that vehicles travel faster on paved roads.

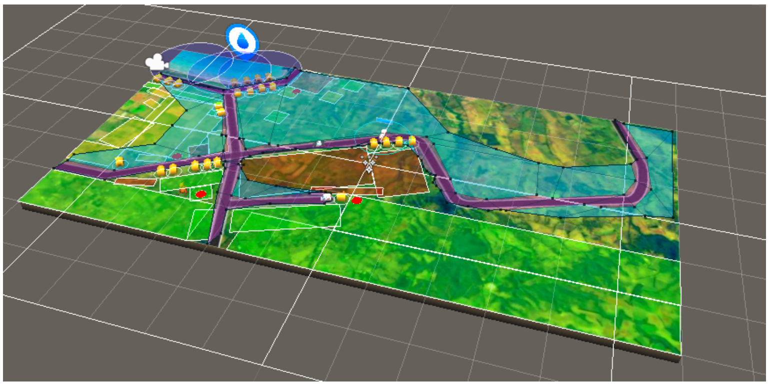

Figure 14 - NavMesh set up of BushfireAR

NavAgent was set up and attached to fire truck game object to allow it to travel around based on the player's commands. When the player taps on a place on the gameboard, that place will be recorded and sent to the NavAgent. NavAgent calculates the best possible route between two points on the NavMesh and moves the game object following the found route (Unity3D, 2020b). A reasonable moving speed was set to balance the usability of the fire truck. Due to the design of BushfireAR, the coordinates of the game board were not constant but were at the location where the user places it in AR space. On the other hand, NavMesh is baked to the place it is originally created. This rendered the NavAgent unable to move on the game board as the game board is not at the same place with the baked NavMesh. To solve this problem, a mirroring system was created with the purpose of translating the fire truck destination positions from the visible game board coordinates to a hidden reference navigation object that matches the NavMesh coordinates (Figure 15). With this design, the NavAgent is actually moving on the hidden navigation object, while the fire truck has a replicated NavMesh local position, and the player can see the fire truck moving on the game board.

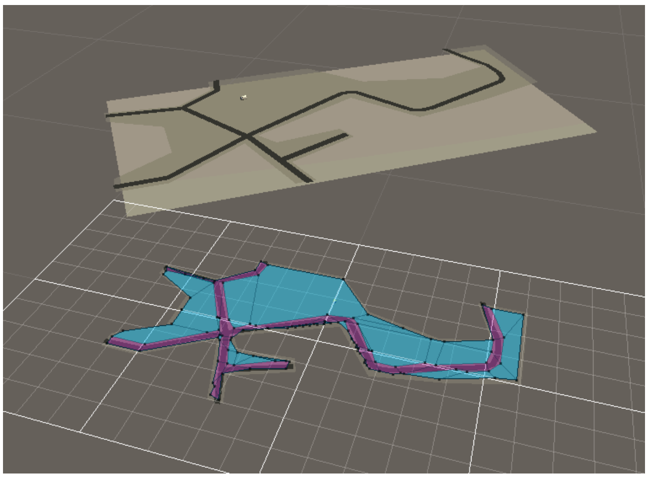

Figure 15 - NavMesh and NavAgent mirroring implementation

The fire truck has an instance of class **Extinguisher** embedded. This is the main script that handles extinguish ability of the fire truck. The main parameters of this script are extinguishing radius, extinguish speed, water capacity, and current water level. Extinguish radius and speed determine the effectiveness of extinguishing. If a **Burnable** object is inside **Extinguisher** radius of effect, its burn level will be decreased based on **Extinguisher** speed. This calculation is also centralised to the main Game controller to reduce unnecessary calculation. The water capacity and level parameters defined how long the fire truck can activate its extinguishing effect. This set up the limitation of the fire truck that contribute to the main game mechanic as well as game challenges. To simplify game interaction, **Extinguisher** will automatically activate its effect when NavAgent stops near a **Burnable** object. This approach eliminated extra actions needed from player to start extinguishing, thus, reduced the game complexity.

5.4.4. Level design tools

In the design phase, there was significant effort spent on designing the game level. The actions required to set up trees, houses, animals, and narrative elements are time consuming and ineffective. The time required to build a game level with hundreds of trees and houses was more than a week. And many problems arose when the level need to be modified, tested, or redesigned. Therefore, game objects were built with great attention to aid level design tasks in the development phase. Debug draws were added to game objects that have effect radius such as burnable, extinguishable, and water source. A coloured circle was added to each of those objects, which helped the designer to understand the impact region of each object, thus, significantly increasing the clarity of the level in Unity editor.

A game object named **TreeBlock** was implemented to aid tree-planting tasks. Placing trees one by one would require a significant amount of time. Therefore, **TreeBlock** is created with settings to plant trees in a specific rectangular area. The designer can change the type of tree to plant, the number of rows and columns of the area, and combined with base game object transform properties such as position, rotation, and scale, to create a forest easily. A randomise function was also added to achieve a noise distribution look to the rows and columns of trees. This game object also has a coloured debug rectangle displayed in the Unity editor to aid map planning. BushfireAR system also took advantage of Unity's Prefab system to "store a GameObject complete with all its components, property values, and child GameObjects as a reusable Asset" (Unity3D, 2020d). Frequently used objects such as trees, houses, and animals were all stored as Prefabs. The game level itself contained the game board, trees, and all final game elements were stored as a Prefab too. By doing this, the game could be placed on a scene to test in the Unity editor where an AR scene could not run. This method greatly helped to speed up designing, validating, and testing tasks.

Most of the game objects in BushfireAR utilised the strength of Unity's inspection window to expose object properties. "When GameObjects have custom script components attached, the Inspector displays the public variables of that script. You can edit these variables as settings in the same way you can edit the settings of the Editor's built-in components. This means that you can set parameters and default values in your scripts easily without modifying the code" (Unity3D, 2020a). This approach greatly reduced the complexity of setting up the game scene.

Narrative elements were embedded to BushfireAR with a simple design of a narrator image and a text box, and a button was added when needed, controlled by the narrative controller game object. This is a

2D UI system that receives and broadcast messages as a singleton. Narrative scenarios were defined with text messages, timing, and links to related game objects. A timed burnable object was designed to handle the fire ignition at a specific time and place. This timed burn object played an important role in narrative scenarios of BushfireAR. When a narrative scenario was triggered, narrative actions as messages were broadcast to the designated receiver. The narrative controller also handled the quest system. It would wait for a specific function call in a game object to be finished before triggering the next narrative action. This simple yet sufficient system helped to provide crucial narrative information to the player as well as keep track of each of the game scenarios' progress.

5.4.5. AR adaptation

To adapt the system into an AR experience, the Unity XR (Unity3D, 2019) extension was used. Unity XR unifies the interfaces of Apple iOS ARKit and Google Android ARCore to create a single interface that can be used in Unity projects.

MAR applications and games have their own unique setup steps:

- Ask the player to scan around. Most of current MAR frameworks are operated by constantly processing the image from smartphone camera feed, combined with motion data to track user movement and display virtual elements on the screen accordingly. By scanning around, AR systems can collect more features points and predict the scene better.
- Ask the player to place the elements onto detected planes. Unlike many other AR implementations that require markers in order to display virtual elements, MAR platforms such as ARKit and ARCore have the ability of scene recognition. Thus, AR elements can be placed anywhere in the augmented real world. The AR system will be able to display the augmented elements by continuously tracking and mapping.

In BushfireAR, those two setup actions were implemented with vibrant visual cues. Feature point clouds and detected planes are visualised with yellow floating orbs and textured planes. The game then projects an indicator that resembles the game board to show how the game board could fit on the detected planes.

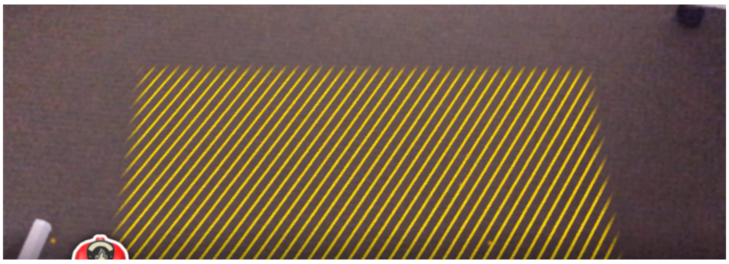

Figure 16 – Game board placement indicator

UI elements of the game are also programmed to improve their readability in the AR experience. The 2D UI will always face the player (Figure 17). This behaviour was achieved by continually calculating and applying the angle from UI objects to the main camera. This ensured the player's attention on the important in-game elements such as water sources, incident places, and highlighted places.

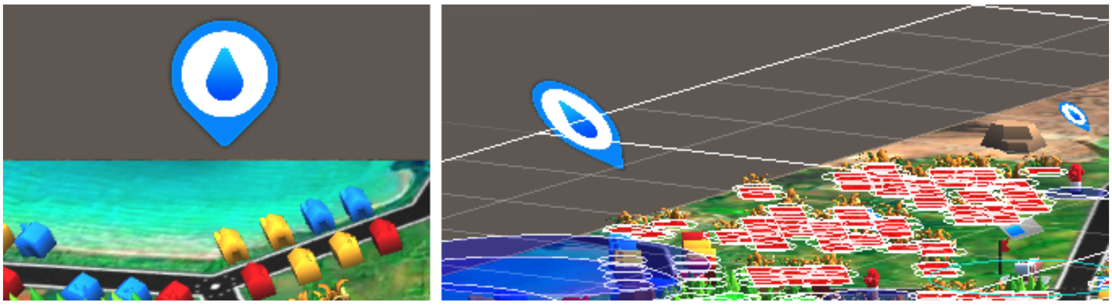

Figure 17 - 2D UI facing the main camera

5.4.6. Player's journey

The game level was design based on different difficulties, bushfire complexity, bushfire propagation characteristics, and fire truck limitations and travel ability. Five scenarios were introduced (Figure 18)

Figure 18 - Game board with 5 bushfire scenarios

- Scenario 1 (Figure 19): A small fire starts in a low-density grassland. The fire will spread to nearby grass bushes but could not reach different forest or houses and animals. This scenario acts as a simple tutorial that introduces the players to game mechanics of bushfire burning and fire truck extinguishing. The firetruck starts at fire station (point A in figure). The narrator will ask the player to move the fire truck to the fire hydrant (B), then to the incident (C).
- Scenario 2 (Figure 20): A big fire (point D in figure) starts from one side of a high-density forest where the other side is connected to the town. The narrator will ask the player to stop the fire before the fire reaches human houses. This quest implies the duty to protect humans and infrastructure. But the fire was designed to spread fast and in a vast area where the fire truck extinguishing area of effect cannot reach. This limitation encourages the player to be more active to intercept the fire or accept that the bushfire cannot be extinguished at every place and focus on protecting essential objects by stopping the fire at a choke point as the narrator suggested (E).

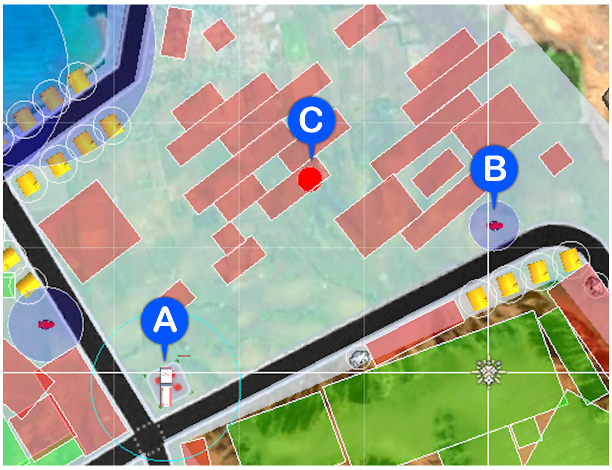

Figure 19 - Scenario 1

Figure 20 - Scenario 2

- Scenario 3 (Figure 21): Fire starts in an unreachable forest (point F in figure) where koalas appear at the woodland edges. The player has to reach the koalas (G) to save them before the fire reaches them because the koala will die instantly when the fire touches them. The narrator will ask the player to save them as quick as possible by moving the firetruck to places where koalas are waiting. This scenario implies the vulnerability of wild animals in bushfire incidents.
- Scenario 4 (Figure 22): A human-made fire (point H in figure) started in the middle of a bushy forest and eventually burned down the vast area where fire truck cannot access. This is the most intense fire scenario in the game in which the player cannot save everything; they have to choose wisely to minimise casualty. On the edge of the forest, there are wild animals and houses to be saved. The narrator will ask the player to act wisely in this scenario. The scenario implies the fact that causes of bushfires sometimes originated from human activities and how hard it is to control bushfire.

Figure 21 - Scenario 3

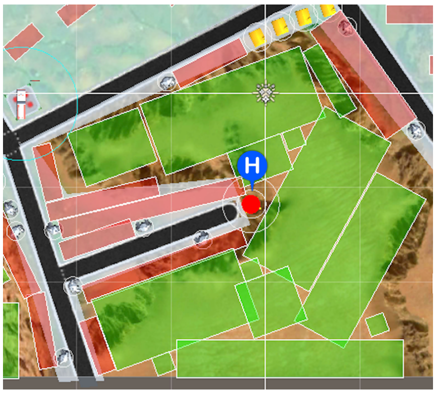

Figure 22 - Scenario 4

- Scenario 5 (Figure 23): The last scenario is an exhibition of the fire fighting aeroplanes (marked as airplane icons in figure) - in this scenario, many fires start at the same time in the area where the fire truck cannot reach. The narrator will tell the user about the water bomber and call for help from them. The aeroplanes then put out the fire. This sequence leads to the conclusion of the play experience (see Appendix C).

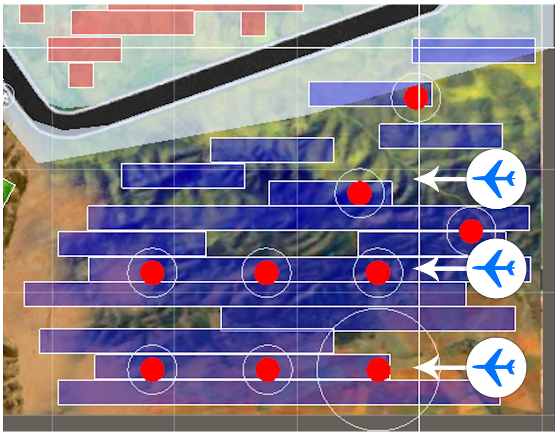

Figure 23 - Scenario 5

The game-over screen will be displayed when all scenarios are over - confirmed by no more fire on the game board (See Appendix C). The game-over screen was designed as a newspaper front page of the day after. In its headline, the newspaper is praising the effort of the player as well as summarising the score in the number of trees, houses, and animals saved next to their total. By looking at this screen, player can have a sense of how good their performance was. The numbers can also be used as a comparison for other play sessions.

5.5. Testing and evaluation

The game was tested and evaluated in a limited playtesters group. This group was formed following the definition of 2nd Circle: Trusted Friends and Tissue playtesters by Bond (2014). This group consisted of trusted friends and family members. They are the first player group that test the game beside the creator. Therefore, observing game testing sessions was one of the most important tasks in the testing phase. By understanding different player approaches to play the game, the game design and interaction could be altered and reconsidered for subsequent iterations. And to ensure unbiased feedback where play sessions are not affected by gained experience between play sessions, this playtester group could only play the game once. They are called Tissue Playtester (Bond, 2014) because they play and evaluate the game once only, just like the use of a tissue. According to Jeremy Gibson Bond (2014), they are critical for evaluating "the tutorial system" and "emotional impact" of the game.

The playtest session started with the participant completing demographic survey and bushfire awareness survey. Each participant was then provided with an executable file for Android to install on their Android mobile phones or an iPhone with the game installed. The testers could then start playing the game. There was one participant who encountered a problem with setting up the AR environment. The problem was identified as a limitation of ARKit system that sometimes detects wrong motion signals that resulted in flying AR elements. The problem was gone after restarting the game. After completing the play session, participants were asked to complete the HARUS and awareness change survey.

Section 6: Results

There are several results collected from the pilot project and evaluation with playtesters group. With the data collected from participants before and after playing the game, the game's design and interactions are validated. The survey that was distributed with the play session contained demographic information, HARUS, and bushfire awareness before and after playing the game (see Appendix D). There were 12 participants who tested the game.

6.1. Demographics

Of the 12 playtesters, 9 were males, and 3 were females. Five of them are Australians, six of them are Vietnamese, and one Chinese. Out of five Australians, four are from a same family with two different generations and an Australian student. The seven non-Australians are international students and their spouses, all of these international students have spent less than two years in Australia. The participants ranged in age from 18 to 41+. According to the result, nine participants were moderate to extremely familiar with AR and MAR. And as the data suggested, seven participants preferred to play games on their smartphone with more than 7 times per week but only less than an hour for each session. All three female participants were reported in this gameplay group. Five participants liked to play games on PC/Mac or game consoles, more than 7 times a week, and played more than 2 hours per session. Since this was only limited group testing, the participants demographic did not reflect the intended targeted audiences of children from age 10-14. The key attribute being addressed with this evaluation was the usability of the system.

6.2. Bushfire awareness change

Regarding bushfire awareness, before playing the game, only 4 participants answered correctly question about hectares burned, 4 on house burned, 4 on human fatalities, and only 2 participants answered correctly the question about the number of animals killed by bushfire. In total, only one participant correctly answered all the questions. When asked about changes to their awareness of bushfires after playing the game, seven participants answered 'No', and five answered 'Yes'. All five Australian participants answered 'No' but there were five non-Australians answered 'Yes'. This result did not directly suggest that the message of the game was not met, only a small number of the participants suggested that playing the game changed their perception and awareness of the dangers of bushfires. This could be due to the differences in information exposure levels of each participants. In five participants answered 'Yes', there were four people thought that extinguishing bushfire is easy. As the results suggested, the bushfire scenarios introduced by BushfireAR might change those participants' awareness on aspects of bushfire and response. There was no sign of connection between AR familiarity or game familiarity with awareness change. Still, the results partly reflected the imperfect effectiveness of the provided experience. On a bright note, this suggested that BushfireAR has the potential to capture some players' attention.

6.3. HARUS scores

The survey then collected data of HARUS - a usability scale survey for HAR applications. HARUS has 16 questions regarding comprehensibility and manipulability usability scale. Perceptual issues and Ergonomic issues can be addressed through questions of the survey (Santos et al., 2014). In HARUS, odd-numbered questions have negative phrasing and even-numbered questions have positive phrasing. For negative questions, a lower score means a better result. For positive questions, higher score suggests better result. HARUS was embedded in the survey of BushfireAR and completed when the player finished the game. The final HARUS results are visualised as a statistical bar chart in Figure 24.

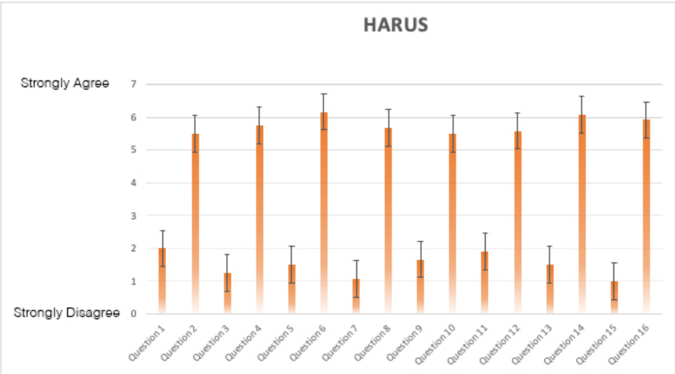

Figure 24 - HARUS average scores

The calculated average HARUS score from all participants that completed the evaluation was 85 out of 100. This means the HAR experience has excellent usability. In the question numbered from 1 to 8, the manipulability of BushfireAR is measured. According to good results of HARUS questions numbered 1, 2, 3, 5 and 7, most of the participants had little to no problem holding the device. Two participants were provided with an iPhoneX and the other participants used their personal devices for testing. Because BushfireAR is a MAR experience, therefore, related ergonomic characteristics belong to the mobile phone. Thus, those high scores of questions numbered 1, 2, 3, 5, and 7 only reflected the good physical design of mobile phones rather than software features of BushfireAR. Good scores in questions numbered 4, 6, and 8 reflected the effortlessness to handle the game. This included touch input of the device and in-game interaction design. BushfireAR was designed to operate under a minimal number of player's actions needed. This decision led to a simple yet accessible play experience as reported by the HARUS score. All nine participants that liked to play games on their mobile phones scored high on questions numbered 4, 6, 8. In the questions numbered from 9 to 16, the comprehensibility of BushfireAR is evaluated. Good scores in question number 12 and 15 suggested a smooth, not laggy game-play experience. This reflects the effort devoted to careful optimisation in the development phase of BushfireAR. Fairly good scores on questions numbered 9, 10, 11, 13, 14, and 16 suggested that BushfireAR in-game UI, game elements, and narrative design had successfully fulfilled their purposes as the player easily understood game elements as well as the narrative intention of the game designer. The five participants identified in 6.1. that played more game than the rest had high scores (>85) on HARUS questions. Even though there was no clear correlation with demographics and awareness change characteristics, the high HARUS score recorded implied that the BushfireAR game design was suitable for a HAR experience with good manipulability and comprehensibility.

6.4 Usability analysis

In this section, correlations between demographics, bushfire awareness changes, and HARUS score results will be further discussed and analysed.

The tester group consisted of 9 males and 3 females. The average HARUS score of male participants was 86, while the average score of female participants was 84. Even though the average score from male participants was higher, the difference is not significant. There was a teenager participant whose score is 90, and a child participant (less than 18 years) scored 83. In the case of the younger one, HARUS scores were not good in the questions regarding ergonomic matters while very good in the game controls and information delivery. This might imply the suitability of BusfireAR’s content in serving its purposes in initial target audience group. Larger evaluation is needed to confirm this statement.

Five participants who considered themselves active gamers (playing more than 7 times per week and for more than 2 hours per session) got an average score of 87. This score is higher than the average score of other participants who do not consider themselves gamers. It is clear that those participants who played more video games had more familiar with games, thus, had no trouble understanding BushfireAR’s game UI, elements, and scenarios, and eventually scored a higher score in HARUS, especially in question numbered 8, 12, 14, and 16 regarding information presentations and game controls. Two participants who are extremely familiar with AR and MAR had no significant increase in their HARUS scores.

The five players who changed their awareness after playing the game also had an average HARUS score of 86. There was no significant suggestion of correlation between awareness changes and HARUS score. As the results suggested, after dividing into groups of different characteristics in demographics and awareness changes, most of HARUS average scores are still 85 which is equal to the whole test group average value. This might be due to the simplified design of BushfireAR in which core game play and narrative elements were carefully considered. Most players had no difficulty understanding and playing the game. The other possible reason of high HARUS score is the portability and capability of modern mobile phones which the participants used to test. The current generation of smartphones have little or no ergonomic issue, which is demonstrated by the extensive design carried out by the major developers of smart phone devices. Thus, a major part of HARUS score, potentially, was not reflecting the usability of the game. This implies a better SG and AR usability scale should be used to evaluate BushfireAR’s functionalities.

In summary, the results from HARUS reflected the ease to use of BushfireAR for different groups of players. Improvements should be made to increase the game effectiveness in raising bushfire awareness. And most importantly, to verify the study, BushfireAR should be evaluated on a larger group recruited from the intended target audience.

Section 7: Conclusion

BushfireAR is a SG aimed to provide an exciting yet informative play session. To achieve its designated purposes, an iterative approach was undertaken to refine the key features of the game. The development of BushfireAR had many challenges. In the design phase, the most challenging task was to decide the look and feel of the game. In the development phase, the most challenging task was to ensure a sufficient gameplay session with high performance on mobile phones. All of those challenges were addressed during the design and development phases of the project. All game assets and game object controller code were designed and implemented to overcome those challenges from their starting points. The game assets were optimised with low-poly 3D models, simple textures, and scalable UI images. The game object controllers were put into a centralised system where complex runtime computations such as fire propagation conditions are calculated at the start of the game. This design significantly reduced the workload required of game controllers. The particle systems were also optimised with centralised design to reduce overheat in each flammable game objects which can be up to thousands at the same time.

The final BushfireAR iteration provided a strong toolset that utilised Unity Editor features to aid the level designing and testing processes. In the Unity editor, level designer can easily place main game elements such as different types of trees, areas filled with trees, place houses, animals, water sources, and create fire ignition points that start at a designated time to create narrative elements. The built-up level can easily be tested in the Unity editor where the BushfireAR game controller system guarantees matching objects placement in MAR play sessions. The players can play the game smoothly on their Android or iOS mobile phones. MAR allows players to place the game board anywhere they want, unlike marker-based AR experiences. The game gave the player a birds-eye view over a small town where bushfire scenarios happened, as well as providing the player with focused, direct control over a fire truck to put out bushfires. Five bushfire scenarios then introduced the player to the game mechanic, implied the intensity of bushfires, the damage it causes, how hard bushfires can be to control, the importance of decision making in such situations, the importance of saving infrastructure and animals, as well as demonstrating the power of advanced fire fighting vehicles. The pilot product is a novel, well-rounded developed project in terms of the art design, game design, game editor, and play experience.

The game then got evaluated in a limited group of trusted friends and family to validate the game design and interaction. Even though playtesters gave neutral feedback on their awareness changing after playing the game, the HARUS survey used to verify HAR usability collected positive feedback with the final score of 85 out of 100. The high HARUS score suggested smooth and pleasant HAR experiences for most players.

The result of the project implied that a larger expanding development and evaluation would be suitable for raising the bushfire and bushfire responses awareness.

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Appendix

Appendix A – Concepts and Inspirations

BushfireAR was inspired by below sources

Image removed due to copyright restriction

Figure B - 1 Game playground reference (123rf.com)

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Figure B - 2 Screenshot from 911 Operator game (jutsugames.com)

Image removed due to copyright restriction

Figure B - 3 Images of board game Hotshots (firesidegames.com)

Image removed due to copyright restriction

Figure B - 4 Zero hour: Virtual heroes in-game screenshot (https://gmpreussner.com)

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Figure B - 5 Fire in video game SimCity 2000 (samertm.com)

Image removed due to copyright restriction

Figure B - 6 Bushfire Rescue Tactics by “Impbox” Jez Kabanov (www.abc.net.au)

Appendix B – Technical feasibility study

Screenshots of author's related projects and technical tests.

Figure A - 1 [AR]achnophobia - A Mobile AR Serious Game for COMP9752 Computer Game Development (2019).

Screenshots of technical tests.

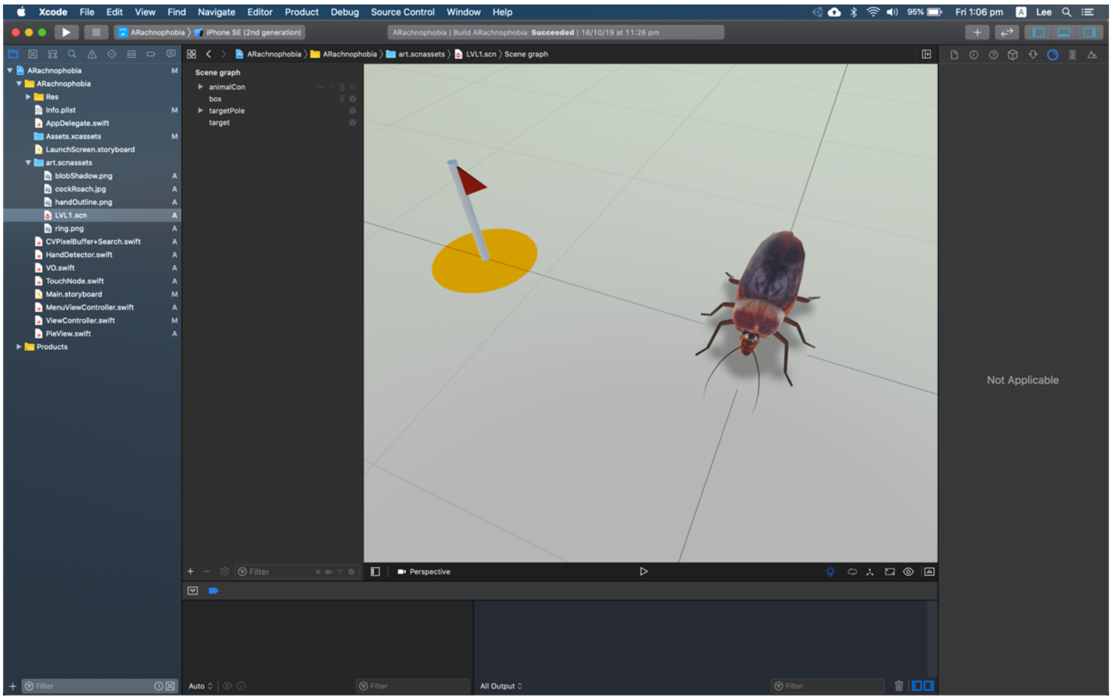

Figure A - 2 XCode AR scene editor

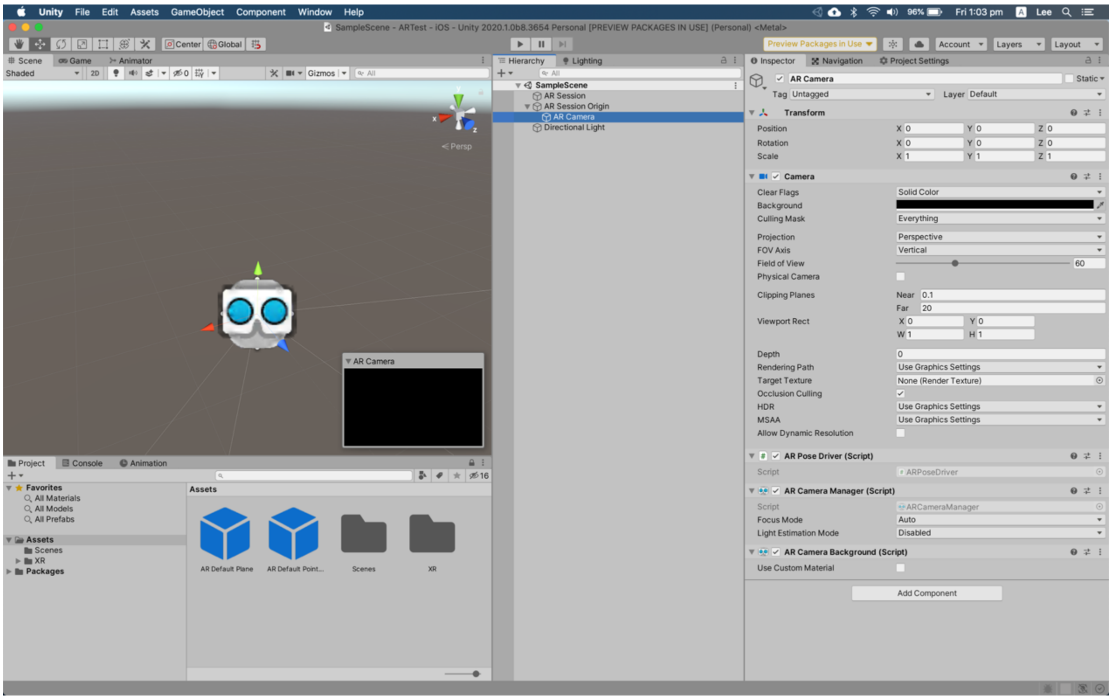

Figure A - 3 Unity editor AR scene workspace

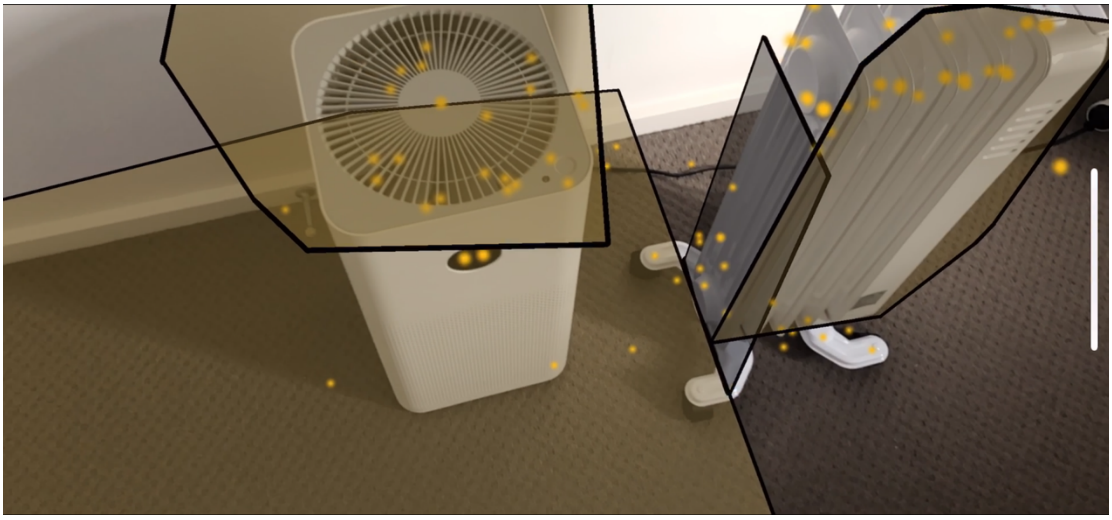

Figure A - 4 AR technical test running on iPhoneX

Appendix C – BushfireAR

Images of prototypes, development, and final implementation of BushfireAR

Figure C - 1 Physical prototype with toys

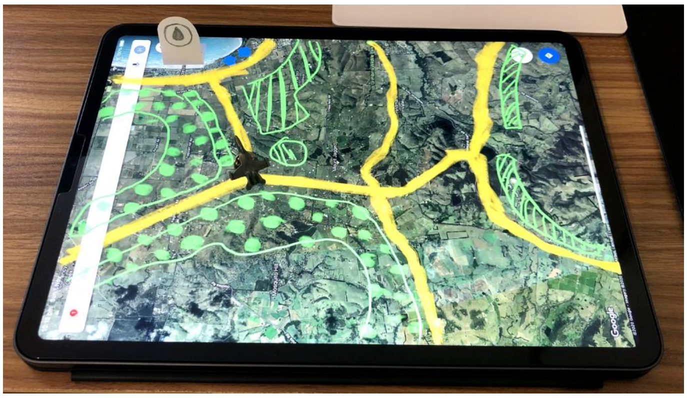

Figure C - 2 Prototype with iPad

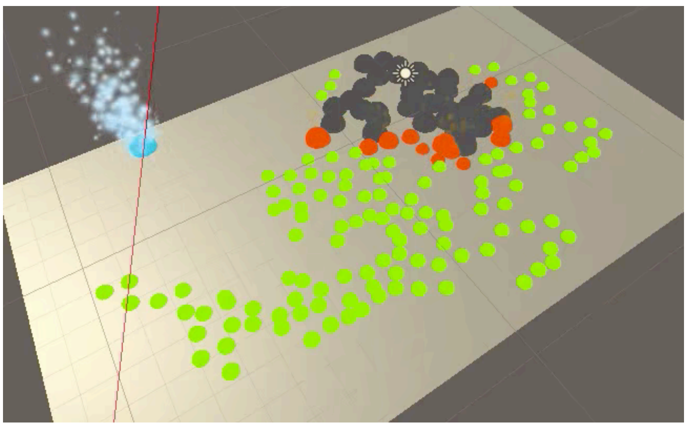

Figure C - 3 Early fire propagation prototype

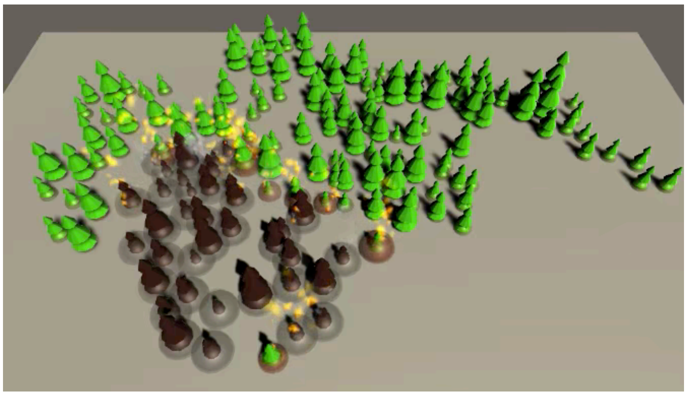

Figure C - 4 Early fire propagation system

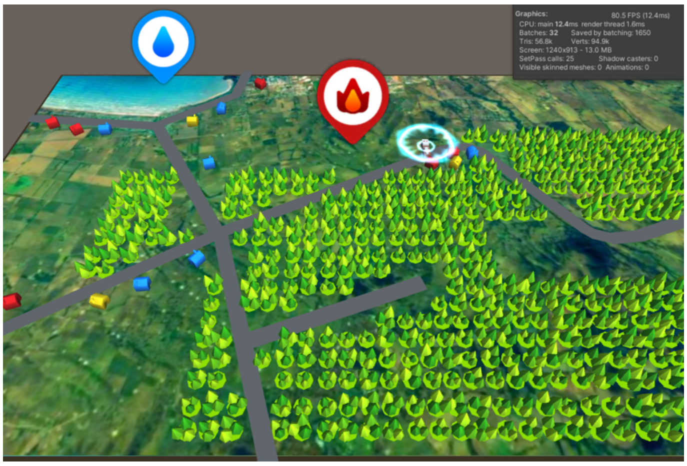

Figure C - 5 Mid-cycle implementation

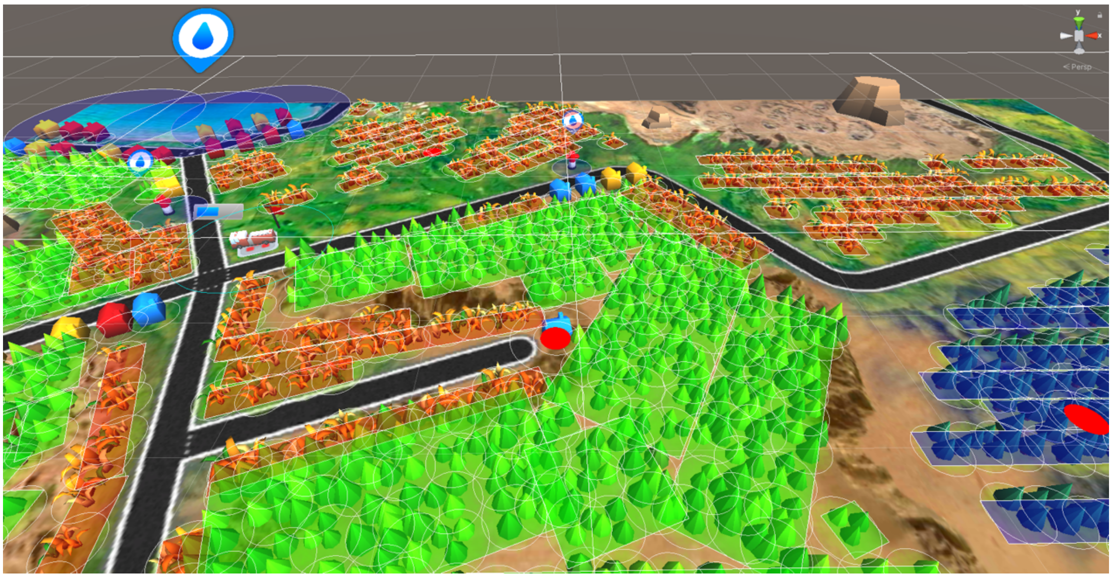

Figure C - 6 BushfireAR in Unity editor

Figure C - 7 BusfhireAR running in Unity Player

Figure C - 8 User plays BushfireAR on iPhone

Figure C - 9 BushfireAR in-game screenshot

Figure C - 10 In-game screenshot

Figure C - 11 In-game narrator

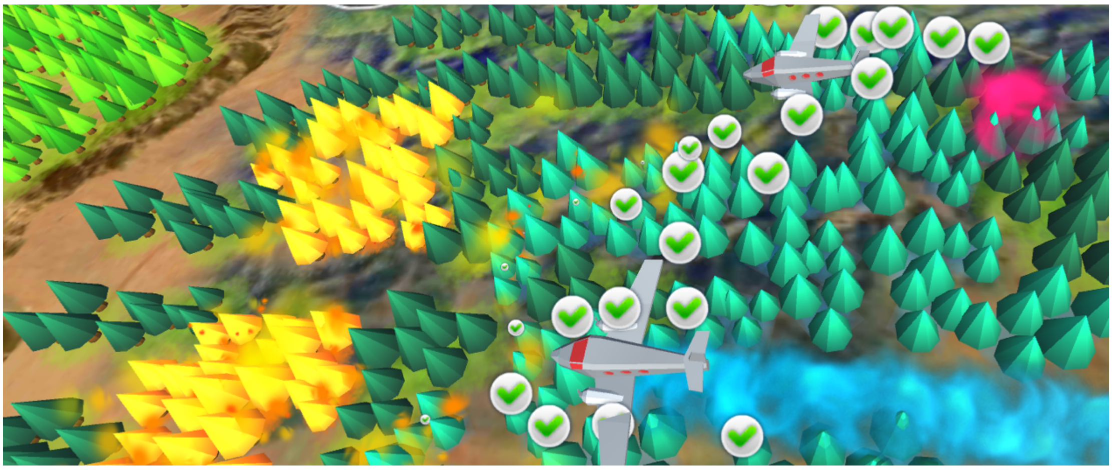

Figure C - 12 In-game screenshot

Figure C - 13 Game over screen

Appendix D – Survey

This is the content of the survey used in limited playtest session of BushfireAR

How do you describe your gender identity? (Mark all that apply)

[ ] Female [ ] Male [ ] Genderqueer [ ] Agender

[ ] Transgender [ ] Cisgender [ ] A gender not listed __________

How often do you play video games?

[ ] 7+ times per week [ ] 5 times per week [ ] 3 times per week [ ] 1 time per week

[ ] Less than once per week [ ] Never

When you play video games, how long do you typically play for?

[ ] 4+ hours per session [ ] 3+ hours per session [ ] 2+ hours per session [ ] 1+ hour per session

[ ] Less than an hour [ ] I don't play games

Which device(s) do you typically use to play video games? (Mark all that apply)

[ ] PC / MAC [ ] Smart Phone [ ] Handheld Device [ ] Gaming Console

[ ] Web Browser [ ] A platform not listed __________

Which of these age groups do you belong to?

[ ] 18-24 [ ] 25-27 [ ] 28-30

[ ] 31-34 [ ] 35-40 [ ] 41+

What is the highest level of education you have attained?

[ ] Postgraduate Degree [ ] Graduate Diploma [ ] Graduate Certificate [ ] Bachelor's Degree

[ ] Advanced Diploma [ ] Certificate III/IV [ ] Year 12 [ ] Year 11 or below

How familiar are you with Augmented Reality?

[ ] Not at all [ ] Slightly [ ] Moderate [ ] Extremely

How familiar are you with Handheld Augmented reality?

[ ] Not at all [ ] Slightly [ ] Moderate [ ] Extremely

What do you think about the damage of bushfire season 2019-2020?

Hectares burned?

[ ] Don't know   [ ] Around 1 millions   [ ] Around 10 millions   [ ] Around 20 millions

Buildings burned?

[ ] Don't know   [ ] Around 100   [ ] Around 1000   [ ] Around 5000

Human fatalities?

[ ] Don't know   [ ] Under 10   [ ] 10 - 50   [ ] More than 50

Animal killed?

[ ] Don't know   [ ] Thousands   [ ] Millions   [ ] Billions

What do you think about bushfire and bushfire fighting?

Bushfire firefighting personals are all professional firefighters?

[ ] No   [ ] Yes

Is it easy to extinguish bushfire when you have equipment?

[ ] Very hard   [ ] Hard   [ ] Easy   [ ] Very easy

What are the direct causes of bushfire? (Please select all that apply)

[ ] Lightning   [ ] Campfire   [ ] Firefly bug   [ ] Electric lines spark

[ ] Cigarette   [ ] Limestone crack   [ ] Animal-caused fire

In which conditions, bushfire will spread faster? (Please select all that apply)

[ ] Hot weather   [ ] Strong wind   [ ] Dry weather   [ ] Steep terrain

Has your awareness or understanding of Bushfires changed since playing the game?

[ ] No [ ] Yes

Handheld Augmented Reality Usability Scale (HARUS) (Marc Ericson C. Santos, Jarkko Polvi, Takafumi Taketomi, Goshiro Yamamoto, Christian Sandor and Hirokazu Kato. Toward Standard Usability Questionnaires for Handheld Augmented Reality. IEEE Computer Graphics and Applications)

Instructions: For each of the following statements, mark one box that best describes your reaction to the handheld augmented reality application.

[Table removed due to copyright restriction]

Thank you!