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APPLYING AUGMENTED REALITY TO STIMULATE USER AWARENESS IN URBAN ENVIRONMENTS

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“Deze masterproef is (ten dele) tot stand gekomen in de periode dat het hoger onderwijs onderhevig was aan een lockdown en beschermende maatregelen ter voorkoming van de verspreiding van het COVID-19 virus. Het proces van opmaak, de verzameling van gegevens, de onderzoeksmethode en/of andere wetenschappelijke werkzaamheden die ermee gepaard gaan, zijn niet altijd op gebruikelijke wijze kunnen verlopen. De lezer dient met deze context rekening te houden bij het lezen van deze masterproef, en eventueel ook indien sommige conclusies zouden worden overgenomen.”

“This master’s thesis came about (in part) during the period in which higher education was subjected to a lock-down and protective measures to prevent the spread of the COVID-19 virus. The process of formatting, data collection, the research method and/or other scientific work the thesis involved could therefore not always be carried out in the usual manner. The reader should bear this context in mind when reading this Master’s thesis, and also in the event that some conclusions are taken on board”

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Abstract

In this thesis, we investigate the use of augmented reality (AR) to increase user awareness in urban environments for aspects such as air pollution. We want to address the questions of user awareness with the use of AR by creating a prototype web application where we will investigate the effect to enhance the user experience by exploiting immersive AR. A web application is necessary to allow platform independent development with facilitating the use of AR. The goal is to explore WebXR and to assess whether users will be interested in the aspects of the urban environment by using newer technology. Smartphones and other mobile devices such as tablets are largely used over the world which allowed people to detach themselves from fixed devices and move around whilst still being connected to the digital world. A web application will be an addition since it will be accessible from everywhere if an internet connection is available. The prototype allows the user to experience immersive AR with their mobile device. The website is minimalistic and the results are provided in a simple way. Alongside the AR experience, a page is dedicated for leaving feedback about the experience or reporting incidents that happen in urban environments.

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1 Introduction

The applications of virtuality to show objects or occurrences within the real world environment dates back to decades ago. One example of virtuality includes showing scores or yellow lines on the football field during a game. People have interacted with computers in many ways and Human-Computer Interaction (HCI) was mostly limited to 2D screens. Advancements in technology now allow for visual simulations using workable models hence the birth of augmented reality (AR) [36]. Boeing researcher Tom Caudell came up with the term *Augmented Reality* while referring to his system of computer graphics that helped factory workers to improve their efficiency by being able to better envision their work environment [2]. Augmented Reality is defined as a system of computer generated graphics or enhancements that overlay an existing reality to enable the user become more useful through its interaction [36]. Nowadays it is possible to interact in 3D and to use gestures. Human Computer Interaction (HCI) has come a long way and can be experienced by using mobile phones and wearable devices such as head-mounted displays (HDMs). In broader terms, augmented reality combines the virtual world with the real world allowing users to interact in real time which allows other technologies like mobile phone applications and HMD systems to overlay virtual objects on existing objects. This overlay allows for interactions that enhance the real-world perceptions which are more advanced than previous HCI. Virtual objects can be anchored to physical objects and they can occlude them or be occluded by them. This occlusion can happen accurately in real-time through the real-time interaction of the virtual and real world. Thereby, the users' experience and understanding of their surroundings is enhanced.

The process of creating augmented reality starts with capturing the real world environment. The virtual environment is modelled concerning the desired effects of the real world since it is the target. The modelled virtual environment is then projected onto the real world. AR falls into the context of mixed reality (MR) which is a mix of virtual and real worlds. Mixed reality are environments where physical and virtual objects interact in real time. Above all, mixed reality goes beyond the aspect of just placing a layer on top of the real world environment and allows for a complete combination of the two worlds. However, there is the aspect of degree of interaction between the user and the virtual world in AR. Often, the virtual world is a simulation of the objects present in the user's environment or complex situation that aims to enhance the user's experience. The past few years have seen a quick evolution in the field of AR with a large amount of use in Smart cities and the control of traffic.

Augmented reality utilises the aspect of telepresence to enhance the user's experience. Silva et al. [42] defined telepresence as a human/machine system in which the user experiences the virtual world in a way that creates the illusion that the user is physically present in the virtual world. AR activates the sensory-motor abilities of the user by providing information on the real world in a way that is very natural. Unlike in virtual reality where the simulation of presence is done using computer simulations, in AR the illusion of presence will place the user at a remote location. The user's problem solving abilities then extend to the remote location as they learn how to use these abilities in the real world environment. The user interacts with an environment that is not entirely real and neither virtual. The basic components of AR, including the scene generator, tracking system and the display all combine to enhance the user experience. The scene generator consists of a computer or application that creates the scene for the user. Scene generators are still growing and there is room for technological advancements. The tracking system is a more challenge aspect in AR since objects in the real and virtual words require alignment. Considering that the goal is usually to trigger the motor and sensory skills of the user, tracking is critical to an AR scene. The most commonly used system for AR is the head mounted display (HMD) that allows the user to view the combined scene. However, developers stumble upon the problem of brightness and field of view with the current display devices. Devices such as HMDs do not provide the desired amount of contrast for the user to blend the real and the virtual world. Developments in AR promise improved systems that will continue to enhance the experience of users and significantly improve problem solving techniques.

AR has found applications in various fields including medicine, navigation, infrastructure development, robotics, architecture among many others. The idea of smart cities is currently catching pace as people use mobile application in abundance and using AR to increase awareness about their environment. Smart Cities use technologies to find solutions that are specific to the people living those cities. These technologies improve the experience of the populations through improved infrastructure, and cleaner environments. As traffic problems and air pollutions continue to affect the quality of life in major cities, the use of mobile phone applications will become critical to increasing awareness and transforming them into smart cities.

1.1 Problem Statement

Air pollution, excessive traffic and human health are some of the challenges that modern cities have to deal with to meet the needed expectations of current and future populations. Collective efforts and cooperation are important in order to solve the challenges and achieve the environmental and infrastructure needs that define a modern city. Current attempts fall short of these since most of the major cities in the world struggle with the problems of air pollution, traffic and infrastructure inefficiency. While cities are continuing to grow and some villages are gradually becoming bigger, technology-based solutions will be necessary to solve the mentioned problems. The United Nations estimates that 66% of the world population will live in cities by 2050 [3]. To ensure a balanced and peaceful living environment, governments will have to stimulate the awareness of the population on matters such as traffic, air quality and pollution and road networks. The increase of smart technologies allows for a better approach in overcoming the challenges and limitations of current technology. Ahvenniemi et al. support the use of lean, integrated and cost effective technologies that will benefit the environmental sustainability and urban populations. These requirements that belong to the general concept of smart cities require a great amount of technological innovation. The focus lies on the well-being of the population by making them aware of their surroundings. There is therefore a need to improve the awareness of the surrounding for theses people living in cities in order to improve the way these people interact. The increase and evolution of mobile phone technologies can provide a long term solution to the current challenges by allowing users to access information immediately. This helps users in making decisions that

improve their surroundings. The opportunities given by augmented reality for mobile phone applications guarantees smart and coordinated solutions. Discussions on climate change and its impact on the environment increased in recent years. Current efforts in reducing the effects of climate change do not show enough result. Pollution levels continue to increase because of the emissions from excessive traffic and human activities. These also led to various school strikes around the world to indicate that a different approach is needed. The negative trends in environmental sustainability need to be reversed through cooperation by implementing methods that allow the input of all stakeholders around the world to be put together. The opportunity for augmented reality usage to create sustainable environments lies in environmental communications. Environmental communication includes the joint efforts of individuals, corporations, and environmental groups to influence actions and decisions that improve sustainability [44]. Environmental communication allows for a structured approach to the climate change topic since it allows for a better understanding of human activities and the impact on nature. Mobile AR consists of the input, the processing and the output. Mobile AR applications use the sensor for input and the processing capabilities of the mobile device for processing. The display gives the output to the user after processing. AR can therefore supplement efforts of creating environment awareness through mobile applications [44]. Since AR is relatively new and still evolving, there are opportunities to increase awareness for city dwellers on issues that cities have to deal with. Mobile phones also play a big part of populations life and the availability and ownership is relatively worldwide. This can increase the opportunity for the message to reach a wide range of people.
The objectives of this thesis are:

- **To investigate:** the possibility of using augmented reality with WebXR and compatible devices to increase the awareness of the surrounding in the urban environment.

- **To develop:** a prototype using of augmented reality in order to improve the user's awareness.

- **To evaluate:** the effect of augmented reality by using the prototype to increasing awareness about aspects, such as air quality in the urban area.

1.2 Contribution

The research on the investigation of Augmented Reality (AR) to increases awareness has a significant role in enhancing the lives of people in everyday life. The first contribution of the research involves the provision of a basic understanding of the applicability of AR in business and other important aspects of life. The research helps to understand certain benefits that are incurred in business such as market expansion, which is a key aspect that relates to the use of AR in a business environment. By increasing awareness, this research helps to take advantage on the usability of the technology to improve everyday lives. The second significant contribution involves the ability to ensure that people become aware of their surroundings through the use of the given technology. The research contributes to increased awareness and acceptance of the technology, where most people consider using technology based on the defined benefits. The primary general contribution of the thesis involves the designing and development of an effective web application that is necessary for mobile AR. The information provided in this thesis helps to understand the needs of using a web app instead of a mobile app. The main reason for using the web app instead of the mobile app is that the web app is not limited considering that it can be used within different operating systems in devices that connect to the internet [8]. In that case, the thesis provides a comprehensive overview of the main aspect that relates to the usability of the web application. Another major contribution of the thesis involves the provision of information regarding different ways that could be relevant to access information. Increased awareness of using AR helps to have an understanding of different measures that could be relevant in accessing information within a given network. Lastly, this contributes to increased visualisation of data, which is a significant aspect of the AR technology.

1.3 Methodology

The methodology to use for the research on AR technology is the design science research methodology (DSRM) [30]. This methodology takes advantage of including different principles and practices that are significant in research. Considering that the research focuses on investigating AR to increases awareness, the use of DSRM methodology helped to capitalise on the impact of the research through the provision of appropriate information that is relevant in the study [5]. The methodology capitalises on incorporating six steps that help to promote effectiveness regarding the kind of information that is obtained in particular research. The first step that is crucial in the methodology includes problem identification, which in this case helps to identify the main issue that relates to the research. Other steps in the methodology include motivation, the proper definition of objectives, design, and development, and demonstration. Additionally, evaluation and communication play an important role in the process of acquiring information in a study that involves the use of technology and the impact it has on people. The main purpose that created the need for the use of DSRM in this study is based on the information that is required for the study. Considering that the study capitalised on investigating a technology that is used in different aspects of life, it was necessary to focus on a methodology that would incorporate procedures and practices that are significant in the provision of the required information. The methodology helped in ensuring that information regarding how AR would increase awareness among people who use technology in day to day activities is obtained. The methodology played a significant role in providing information on the practical application of the research in life [20]. The methodology provides a significant model for the research and helps to promote the impact of research.

2 Background

When Tom Caudell designed computer graphics to assist factory workers envision their work setting, his intention was to enhance efficiency in production lines [2]. First implementations for AR, however, began in 1957 through basic cinematographic experiments. Ivan Sutherland came up with a virtual window that allowed the user a glimpse into the virtual world [2]. The work, however, did not receive much attention because of the low computing capabilities at the time. Growth was slow until 1992 when Louis Rosenberg developed complex robotics for the workplace that processed 3D graphics for improving the productivity of workers [9]. A breakthrough in AR was realised in recent years as giant technology companies such as Google and Apple took a great interest. Google's release of the ARToolkit and its availability to Adobe Flash meant that developers could access the tool for creating AR applications for the web and other devices. However, the progress was still slow as most developers were unfamiliar with the toolkit. The launch of Google Glass in 2013 meant that users could experience AR with the portable device [40]. The project did not achieve the intended success and Google had to make various modifications to Google Glass to improve its appeal. Microsoft's decision to support AR gave the technology a push as more developers could access the developing tools. Apple provides its ARKit for developers to create apps for its iPhone and iPad devices. As technology companies continue to improve the processing capacities for their devices, more applications will be created, and this will stretch the capabilities of AR even further [9]. The future of AR, therefore, looks promising due to its applications in almost every field.

AR has the potential to protect and preserve the world's cultural, biological and historical heritage, including urban centres, and agricultural and wildlife environment. Art and cultural heritage are essential in developing smart cities. These heritages control what needs to be preserved and protected based on the values assigned to them. It is necessary to improve awareness in the public to achieve these goals and ensure well-being and the transfer of these cultural traditions to the next generation. AR presents a potential instrument for analysing the environmental issues and educating the population about the importance of protecting the environment. Most of the technology for AR is still under development, however trends over the past years show that certain major improvements can be expected which will gradually change the way users use AR technology. Users currently have two options when using AR as illustrated in Figure 2.1, either optical see-through (OST) or video see-through (VST) display depending on the information needed to use AR. OST displays allow a small amount of light to pass through half transmissive elements such as half see-through mirrors to let the user see the real world. Simultaneously, an image is being generated and displayed on the same display by a component that is located overhead or on the side of the display. VST uses a sensor to capture the real world which is displayed on a screen where it is being overlaid with virtual elements in real-time.

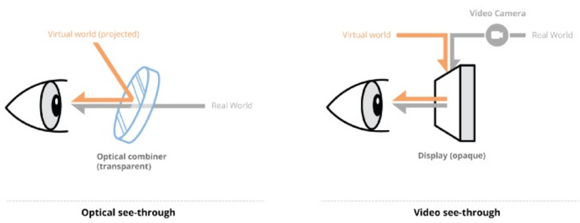

Figure 2.1: OST & VST visualisation

However, there are trade-offs for each of the two choices considering differences in flexibility, the field of view that the equipment is capable of achieving and the resolution [42]. Selecting the most suitable equipment and software depending on the information to input and the display plays a key role in achieving successful solutions. Advancement in mobile technologies and the availability of different applications opens up a great number of opportunities to use AR for awareness on various aspects of cities. There is also a possibility to revolutionise the way people can access information with the continuing improvement in AR. It is important to note that major technology companies such as Google, Apple, and Samsung are investing in the development of AR technologies [36]. Apple's ARKit and Google's ARCore will improve the progress of AR technologies and introduce a new era of AR with their contributions to mobile devices.

2.1 Types of AR Applications

Various augmented reality companies focus on providing applications that are easy to use and enhance the users' perception of their surroundings. These are applications that the user can easily download and use to acquire information. Depending on the purpose of the type of AR technology, four main classifications of AR exist;

- Marker-based augmented reality
- Markerless augmented reality
- Location based augmented reality
- Projection augmented reality
- Superimposition-based augmented reality [15].

2.1.1 Marker-based Augmented Reality

Marker-based AR also referred to as Image Recognition AR due to its mode of operation provides information about the object after scanning a marker as shown in Figure 2.2. This technology uses a camera linked to the AR software to identify AR markers. The image is then viewed on a screen in real-time or afterwards. The simplest forms of marker-based AR markers are two dimensional QR codes or pictures that appear in black and white. The user is able to rotate the device that contains AR software to get a glimpse of various parts of the object which allows the user to acquire information from various angles. Limitations of these types of AR lie in the type of software used. Notably, the developer has to maintain simplicity for easier error detection and correction. Marker-based AR has applications in various fields due to its characteristics. Because of its ability to identify an object and provide information on the screen, it finds use in marketing, education, entertainment and many other fields [21].

Figure 2.2: AR projection on a marker

2.1.2 Markerless Augmented Reality

Markerless AR does not require the device to have prior information of the user's environment before overlaying the virtual content on the users reality. It uses cameras and sensors on the mobile device to map the environment of the user. The AR application on the phone then reads and processes this data to provide the user with virtual objects that fit into the context. As such, there is no need for a marker to process the information as is the case with marker-based AR. Subsequently, markerless augmented reality has seen an increase in use with its compatibility for smartphones that provide location service. Since it uses a camera and location features, it enables users to analyse interesting objects within their environment while also envisioning advanced features. Apple's ARKit and Google's ARCore are some of the most used markerless AR with millions of people using them on their smartphones for gaming, marketing, education and various other experiences.

2.1.3 Projection-based Augmented Reality

Projection-based AR works by focusing light on a surface while the user touches the illuminated surface by hand. The projection of light works by creating an illusion that can be used to enhance the experience of the use as shown in Figure 2.3. This is done by creating deceptions about position, depth and distance of objects. The technology is widely used in the film industry and in entertainment. The optical illusion can also be used to create larger objects that are then used for studying, training and decision-making [25]. The difference from ordinary lighting techniques is that projection AR allows for graphical representation of objects in a sense that allows for alteration of different degrees of illusion. Projection AR is also capable of high definition images and videos with time. This technique can be applied to improve the immersion of the user in the activity which is difficult to achieve with normal lighting [25]. However, projection-based AR has its limitation which need to be overcome in the future to increase application design. Existing techniques are difficult to apply when mapping occurs on flexible objects like clothes since their shapes change constantly. Other objects like cylinders may look complex in shape, but their surfaces and movement are easier to track which makes it easier to map. Dynamic objects are also difficult to map using projection AR due to their rapid movement. There is still room for further development of this type of AR.

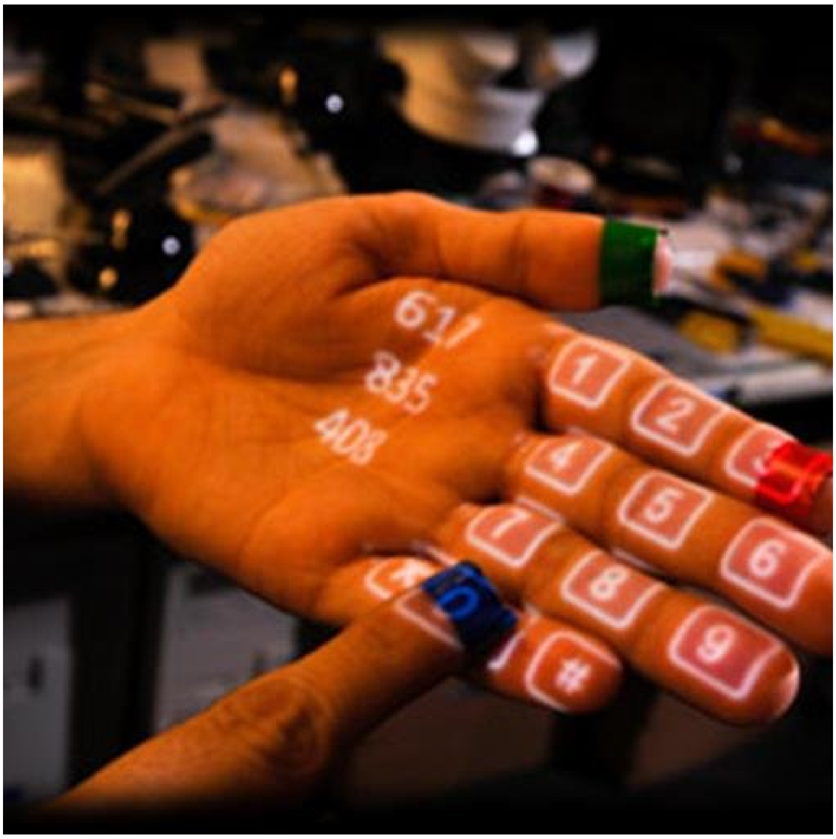

Figure 2.3: Projection augmented reality

2.1.4 Superimposition based Augmented Reality

Superimposition Based AR uses object recognition to partially or fully replace the object in augmented view. The complex application acquires information about the object and develops an augmented view based on the object's position and other features [18]. A very important point is that the application must recognise the object to superimpose to something at real-time. Superimposition Based AR has wide uses in medicine, military, entertainment and filming. For instance, Figure 2.4 illustrates how broken ancient monuments can be brought back to life using this technology which allows the audience to experience what the objects looked like in the ancient time. Another interesting application is in tourism where it is possible to create a virtual reality of a wild animal. The user experiences a close proximity of a reality that is almost impossible in other situation.

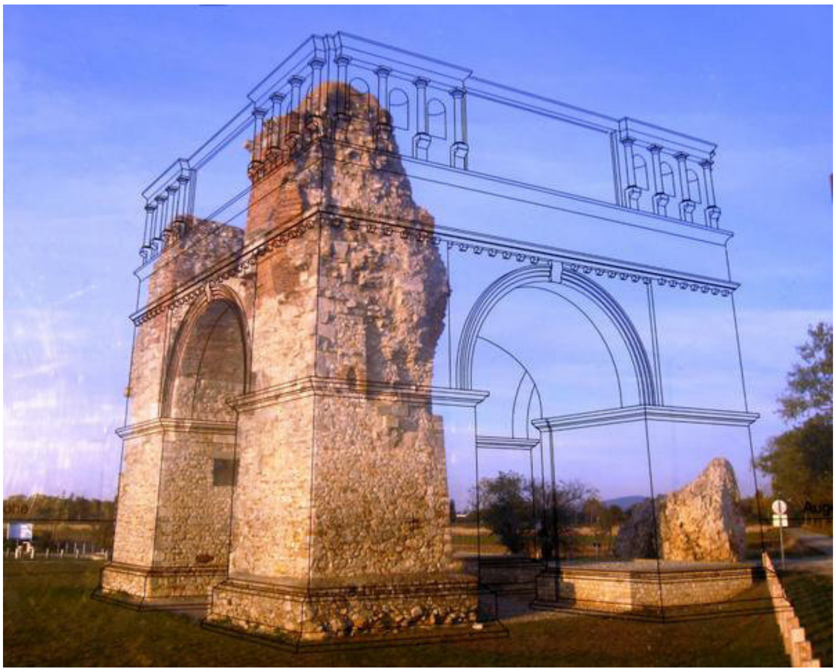

Figure 2.4: Overlaying an old artefact

2.2 Augmented Reality Development Tools

Augmented reality development tools are the platforms that programmers and experts use to develop applications for different devices. A major drawback to the rapid development of AR application is the experience and time required to develop the applications. Typically, AR authoring tools range from low to high level depending on their content design characteristics [37]. Selecting the best AR development tools requires knowledge of its feature and its compatibility with the intended app. Common tools include Vuforia, ARToolKit, Google ARCore, Apple ARKit or Wikitude. This section will discuss various AR development tools available for developers together with their strengths and limitations.

2.2.1 Vuforia

Vuforia allows developers to develop AR applications for Android, iOS and the Windows platform. Vuforia was created by Qualcomm but later sold to PTC which made improvements that increased its popularity in mobile app development. The software development kit (SDK) captures images and other 3D objects using computer vision technologies. Vuforia allows the developer to upload virtual images while at the same time placing the real object in the view of the camera and moving them appropriately. In essence, the toolkit accepts both 3D and 2D images with a frame. Typically, the toolkit divides the data into four parts for easier processing including the input, database, tracking and matching, and render output. The mobile phone camera capture the image before it is compared with similar images in the database of the application. The app then adds virtual objects to the image according to the set guidelines and renders the output for the user [39].

- Advantages

  1. There is a lot third-party material that developers can benefit from on the Vuforia platform.
  2. Vuforia allows different functions for AR; a significant amount of applications can be created. Notably, its functionalities range from tracking horizontal planes to the recognition of objects.
  3. Beginners can benefit from the free version, which is easily accessible online.
  4. Vuforia recognises a wide range of Android and iOS currently on the market; millions of users can download applications created on the platform.

- Disadvantages

  1. The code used by Vuforia is bulky and can be tedious to write. For instance, when creating an app with Swift on iOS, the devel-

oper has to bridge between Swift and Objective C, which becomes tiresome.

2. Tracking markers in Vuforia is also tedious, often requiring the developer to write up to 800 lines of code.
3. It is often difficult for Vuforia to connect to native modules.

2.2.2 ARCore

Google launched ARCore as an AR app development platform where developers use a variety of APIs to allow the phone to sense the environment. The core capabilities of ARCore are environmental understanding, motion sensing, and estimation of light in the environment. Motion tracking uses the phone camera data to allow the position of the phone relative to the other surfaces to be acquired [46]. Environmental understanding, on the other hand, tracks the size and shapes of surfaces and enables the applications developed with ARCore to detect common objects like tables and cars. The lighting condition, using sensors of the phone is also a critical feature of ARCore. ARCore uses light estimation in order to gather the light condition information of the environment. The orientation of the phone and other features in the environment provide relevant data for the AR application to overlay the virtual world over the reality in the environment.

- Advantages

  1. ARCore comes as an integrated part of the Android operating system of the mobile device.
  2. The integration of ARCore into Android improves the accessibility of applications developed using the toolkit. Over 100 million Android users can access applications for this tool [29].
  3. Google, who are the providers of the ARCore platform, are the leading providers of AR technologies. AR application developers have therefore a steady platform to support their talents.
  4. ARCore is simple to use with Unity wich allows developers to make AR appplications with Unity 3D to enhance the user's experiences.

- Disadvantages

  1. ARCore has a limited number of supporting devices, notably Google pixel, Pixel SL, Pixel 2, and Samsung Galaxy 8. Very few people own these devices compared to the number of developers, which limits the use of ARCore.

2. ARCore is integrated into Android and it is impossible to use with non-supported devices.
3. The non-compatibility of ARCore for Apple devices means that its competing tools, such as Apple's ARKit, can provide solutions that can make ARCore less desirable to developers [29].
4. Developers who desire to use the ARCore tool for developing AR applications without supporting devices are left with the option of using Android Simulator, which has limited capabilities and is still in its development stages.

2.2.3 ARKit

Apple's ARKit allows developers to create AR applications on iOS using iPhone and iPad devices. Since the tool only runs on Apple's A9 and A10 processors, it is only available for iPhone 6S and newer devices [31]. The different features of ARKit are environmental understanding, motion tracking, and rendering. Using the devices' camera and other sensors, the device position relative to its point of start allows for capturing of 3D information. The tool does not require any prior information since the camera enables tracking from a designed start point. Scene understanding also allows the camera tool to identify horizontal and vertical planes within the immediate environment. The light entering the camera allows the processor to determine the amount of light within the environment. The rendering functionality means that information flows between the cameras and renderer such Unity at a constant rate and is therefore fast.

- Advantages

  1. Developers do not become subject to any extra charges as in third-party development tools since Apple provides ARKit for its iOS devices.
  2. ARKit allows for quick development of applications with supported devices that have the Apple A9 and Apple A10 processors.
  3. Since the needs of AR are rapidly growing, the effort of Apple also continues to improve the abilities of ARKit.
  4. ARKit allows developers to create applications at a faster rate since its code is less bulky as compared to other development tools.

- Disadvantages

1. ARKit is only supported on newer Apple devices, thus leaving out iPhone six and its predecessors. The tool kit also not available for Android users.

2. Due to the heavy reliance on its tracking capabilities, ARKit sometimes performs poorly in environments with many objects or poor lighting.

2.2.4 ARToolkit

ARToolkit is an open-source development tool for AR available for PCs and mobile phones. Developers write code that allows 3D programs to be connected to an AR marker that exists within the device environment [12]. Typically, ARToolkit works by reading the scene from the position of the marker. The ARToolkit then visualises the virtual scene into reality. Smartphone devices use GPS for location and tracking the environment to provide the toolkit with information about the relative position of the device.

- Advantages

  1. ARToolkit is a developing open-source tool which gives the users opportunities to develop different applications according to their interests and needs.
  2. ARToolkit offers different versions online; developers can therefore create standalone applications for web purposes or mobile devices.
  3. The online availability of the tool allows for documentation of its capabilities and processes; user who intend to learn can benefit from these sources.
  4. ARToolkit is fast and precise and therefore allows developers to create applications and test them within a minimum of time.

- Disadvantages

  1. The tool has marker limitations that undermine the tool's ability to read data from the real environment.
  2. ARToolkit also relies on good lighting conditions and performs poorly in environments with low light.
  3. There are restrictions on camera range which cause difficulties in the movement of the device.

2.2.5 Wikitude

Wikitude is an SDK for augmented reality that allows users to create applications using motion tracking, scene understanding, and estimation of light within the environment. Wikitude combines development capabilities with other cloud services that enables users to use its studio without necessarily writing code. The AR editing services in its online studio allow users to add videos and pictures without any expert skills.

- Advantages
  1. The developing stool is available for Android, iPhone, and PCs which makes it flexible for different users.
  2. The toolkit is easy to use, allowing inexperienced developers to develop their AR application.
- Disadvantages
  1. Wikitude is a third-party tool where users are subjected to extra charges in order to access its full capabilities.
  2. The tools lack originality since it combines the functions of various other AR toolkits, making it vulnerable to bugs.
  3. Wikitude is less preferred for expert application developers due to its weaknesses.

2.3 WebXR

WebXR is an upcoming web design trend and API which allows a developer to integrate the aspect of virtuality in websites. The concept of using a web browser for virtuality was already incorporated in WebVR which was announced in 2016, however the limitations to only use VR caused WebVR to fall behind. WebXR has the advantages of supporting both AR and VR thus superseding WebVR. XR refers to extended reality, which is a technology that integrates augmented reality and virtual reality to improve the user experience and to focus on the increased awareness of trending technologies. The development with WebXR focuses on the aspect of positional tracking or the use a fixed display with technology that supports head tracking [26]. The characteristics of WebXR includes the ability to recognise compatible AR or VR devices, hence the scanning for compatibility before engaging in any connection. The second major characteristic of the technology is that it can render 3D scenes at an appropriate frame rate. For instance, the technology focuses on approximately 90fps for headsets [16]. The main advantage associated with the technology is that it provides users with the ability to view content without the need to install additional plug-ins. The advantage helps to exploit the effectiveness of virtuality considering that it is compatible with AR and VR devices. While WebXR is creating an interest in AR for webdevelopers, it is still in its early stages.

2.4 AR Devices

AR promises to become the most widely used technology in the future. Stockinger [43] noted that most of the current AR technology is adapted for the industrial sector, but with the increase of usage in tourism, film, entertainment, travel, military, and more fields, AR promises to spread to every aspect of future developments. Achieving awareness about people's surroundings in cities, together with the development of the smart cities, will directly benefit from the potential of AR. As developers continue to invest resources in developing AR applications for daily use, people living in urban areas will interact with AR at different levels. The use of mobile phones in AR is likely to increase as well as other hardware AR devices. This section discusses various AR devices and the way they can apply in improving awareness in urban areas to transform them into smart cities.

2.4.1 Microsoft Hololens

Microsoft Corporation launched Microsoft Hololens [1] for user experience using a transparent lens to experience holographic content. It consists of light sensors, a high definition camera, and a processing unit. Hololens scans the user's real environment and processes it in real-time to overlay it with the virtual environment for the user's experience. The device displays the virtual environment to the user as 3D holograms that appear as if they are present in the real world environment. The most common use of Hololens in manufacturing is the real-time modification of models to suit the needs of customers. Hololens also finds use in entertainment, such as having a virtual pet walking around within the house or watching movies on the house wall. Hololens can be used in creating awareness of the dangers of pollution by augmenting the possible effects of excessive pollution into the present physical world.

[1] https://www.microsoft.com/en-us/hololens/hardware

2.4.2 Google Glass Enterprise Edition

Google Glass Enterprise is a hands-free AR device that allows the user to visualise the virtual environment into their physical surroundings. The device allows the user to retain focus on the activity in front while also providing commands using their voice. The device was initially a failure due to infringement of privacy by taking pictures and recording without consent. Google moved swiftly to correct these anomalies, and the device has found uses in industry, medicine, marketing, among other fields. Most notably, the device enhances productivity by allowing the user to work while still connected to the virtual world. Google glass can become useful in the control of traffic in urban areas as the controller observes the perfect flow and applies changes that make it easier for motorists to navigate various routes within the city.

2.4.3 Epson Moverio

Epson Moverio has a slightly different view from Google Glass because of its capabilities in portraying the real world alongside the virtual world. For example, the user can use the device to fly a drone by accessing information about the sky while also observing navigation data for the real situation. Epson Moverio can be used in urban areas to determine the flow of people at different times. It can help to develop future strategies that make them more aware of their locations and other features of the city.

2.4.4 Magic Leap One

Magic Leap works by bringing virtual reality to the real world such that the user views objects in 3D relative to the physical environment. The futuristic technology overlays the virtual objects into the real world and also allows the user to interact with the objects actively. For example, the user can observe the solar system in the classroom while studying its different characteristics. It is therefore possible to use the technology in education by allowing learners to experience different aspects of their environment, ranging from good to bad.

2.4.5 Smartphones

The use of AR on smartphones is among the most rapidly growing and promising methods of easing access to AR technologies. Smartphones have all the basic features for AR, and developers can benefit from AR applications that enhance user experiences when using phones. For example, AR is used in marketing by allowing the user to arrange furniture according to the setup of their rooms. Similarly, gamers are able to interact with virtual characters as if they are in their real environment [10]. As the processing power of smartphones increase, more applications can be developed that enable smartphone users to enhance their physical environment using information from virtual reality. AR can apply in creating smart cities using mobile phones by making crucial data available to city dweller depending on the intended purpose. For instance, when the intention is to improve public transport and reduce congestion, users can access various locations in the city and select areas where they would prefer to access public transport. This makes it easier for the government to plan transport routes and terminals. Alternatively, AR can be applied to improve city environments to restrain climate change. Information on the most polluted areas can help residents to select areas where they prefer to set up industries. As a result, the government's plans infrastructure and industries according to the interests of residents to stop harmful effects like air pollution.

3
Related Work

In this chapter the goal is to discuss existing research on AR technologies for mobile phones as they are applied to meet the needs of urban populations. Navigation in cities is a significant challenge given the problems of overcrowded cities, traffic, and challenges by individuals in accessing certain physical areas. Different navigation technologies are available to provide solutions to the existing challenges. Research on awareness of city populations about their environment and levels of pollution has also incorporated AR technologies to improve the knowledge for the population. This section, therefore, explores existing research on aspects of awareness about the physical environment as well as pollution in cities. This section will also assess the level of success of various studies relating to the awareness and development of modern cities using AR on mobile devices.

3.1 Location-based AR

Studies on AR and the way it applies to human experiences have covered many aspects of modern societies. The use of AR goes through several aspects of modern societies such as transport, infrastructure, manufacturing, entertainment, tourism and travel [42]. Improving the experiences of residents in urban areas has also received the attention of researchers with several studies focusing on the use of AR in making smart cities a reality [4]. The use of mobile phone technologies with AR for the identification of landmarks and other important areas in the city is possible with the proper applications that fulfils these capabilities. Amato et al. noted that mobile phone technologies could become useful in saving the time that residents use to access business and other features that they are not familiar with within the city. For instance, the user can simply point the camera to a feature, and details will appear about its identity and other relevant information on the screen. There is, however, the problem of misalignment of information between the real environment and the virtual scenes when the user is far from the desired location. A possible solution to the problem involves content-based retrieval of images based on the ability of the phone's application to identify the feature and place it on the virtual scene [4]. The similarities between the real and virtual world becomes useful in guiding the user to the desired location. Location-based AR technologies for smartphones were also considered by Muchtar et al. [28] who stated that most of the current mapping technologies within cities are not dynamic enough to meet the changing needs of the city dwellers. As a result, users experience difficulties in finding assets like Mosques and hospitals, thus ending up wasting a lot of valuable time. A proposed solution for the dynamic problem that uses AR for mobile applications is to use GPS to give interactive information to the user [28]. The proposed system works by capturing the image of the user's current location while the GPS tracker provides the exact coordinates of the place. These coordinates serve as the reference point for the application to search the nearest intended location from the application database. Once the location is identified, the positioning process begins where the virtual element is augmented to the physical place while the user receives instruction on the best route. This also allows applications overcome the challenge of non-interactive location mapping, which is sometimes difficult to follow. On the other hand, mobile location-based tools can also be applied in limited spaces to provide guidance for individuals who are unfamiliar with the environment [36]. The research provided a mobile application that utilises geographic information system (GIS) to help the user easily locate assets within the university. The applicaiton is almost similar to that developed by Muchtar et al. [28], although the main difference lies in the utilisation of GIS location data. Once the application has acquired the exact location of the user through the GIS, it superimposes the virtual content to the physical location and guides the user to the intended target. The application proved to be useful for new students and visitors to the campus and has the potential to succeed in smart cities in provide direction using interactive means. Research into location-based AR for pedestrians has received strong attention with the idea of smart cities, which facilitates the movement of people. Brata & Liang found that pedestrian navigation applications improved the actions and decisions of the user hence saving time and reducing human and car congestion. These applications utilise the processing capacity of mobile phones to guide the user to their point of interest using real-time interaction. Unlike standards of navigation applications, pedestrian navigation technologies utilise user behaviour data to enhance the experience [7]. The user-centred system may work by providing several actions with the degree of efficiency hence allowing the user to keep the final decision about the most suitable option. Understanding the effectiveness of location-based AR applications is key to their deployment in helping to solve navigation problems in urban areas. Ramos et al. [36] highlighted the importance of usability for AR applications considering the environment where the applications can be applied and the population characteristics. GIS location applications were more effective in finding assets than map view applications due to the interactive nature of AR applications. The effectiveness finding is supported by studies by Brata and Liang who stated that pedestrian action greatly improved when using location-based navigations applications. There is, however, a part of users that noted weaknesses that require improvements to make navigation applications more effective. For instance, when the point of interest is behind another building, the user may experiences difficulties pinpointing the location without exact GPS coordinates [7]. The limitation shows that there is still room for improvements to make location-based AR applications more effective. Evidence shows that AR navigation uses significantly lesser time than when using the map view [36]. The adoption of various location-based navigation applications promises a reduction in the amount of hours spent searching for assets or grappling with congestion problems in urban areas.

3.2 Augmented Reality in Smart Cities

Concepts of smart cities that are most relevant to AR correspond to more effortless mobility for residents, a clean environment for the population, and quality living. People's mobility receives the highest attention when creating smart cities, as demonstrated by studies on location-based AR for navigation [7, 36]. Arguments against the excessive use of technology in urban areas, however, emerged in recent years. Salvini [38] stated that AR technologies for smart cities have their downside, and too much utilisation can have harmful effects on the way people interact with their real environment. The focus of individuals becomes divided when they use phones or tablets to navigate, hence they are more likely to fail to notice traffic coming from their blind side. This divided attention puts them at greater risk of being involved in accidents or making the wrong decisions. Thus, technology should be within the limits of human behaviour and capabilities such that their normal thinking processes and decisions making is not undermined [38]. The appropriate approach is to develop AR technologies that are human-oriented. Aggarwal & Singhal investigated the negative effects of AR on the normal activities of humans. They noted that the AR game, Pokémon Go, is responsible for various accidents due to the gamers attention being shifted to the screen of their phones instead of focusing on their surroundings. Similar effects can occur with travellers who use mobile phones and tablets that may misinterpret the distance of approaching vehicles; thus, performing poorly in reaction time [2]. The dangers posed by inappropriate use of AR technologies for mobile phones and tablets can be fatal for the user. These risks undermine the advantages of AR technologies; thus, highlighting the need for reducing efforts that enhance the safety of users. Currently, safety efforts for users are not receiving deserved attention as most developers concentrate on improving the user experience in their familiar environment [38]. The lack of guarantee for user safety is therefore a threat that can undermine the promising future for AR in smart cities [2]. Creating AR technologies for mobile devices that incorporates user safety measures such as warnings on the screen to avert danger can significantly reduce the risks of poor attention for users. Despite the shortcomings of AR technologies with regard to distractions caused by the lack of focus, AR applications also promise various benefits for smart cities. AR application in tourism can improve the perceptions of visitors and enhance their experience as they visit various sites [19]. City heritage can be destroyed either partially by accidents or by natural disasters. AR, therefore, becomes critical to envision their original design either for reconstruction or for tourists to view their initial state. Location-based AR applications described by Brata & Liang [7] and Ramos [36] for outdoor movements can also be adapted for indoor tourism activities. Visitors to museums have several sites to visit within a limited time; hence AR navigation techniques can assist them in finding the most preferred locations. Using cameras as visual sensors to provide direction to tourists for their point of interest, thus becomes a practical idea [24]. A combination of indoor AR applications and navigation applications by using AR throughout the city can be crucial in advancing the tourism sector of smart cities. The essence of smart cities is usually to provide equal opportunities for different people regardless of language, physical, and social status. Various AR applications have been developed to bridge the gap in movement and experiences of people with challenges in movements such as the deaf and blind as well as older people [19]. De Oliveira et al. [11] suggested a navigation system for people in wheelchairs. The system identifies the location of the individual within the city and calculates the most appropriate routes which the user can utilise without movement difficulties. Such technologies improve the living experiences of users since they are able to independently perform most functions that would otherwise require the assistance of others. Advancements in technologies that enhance the interaction of people with auditory disabilities within their environment highlight the relevance of the incorporation in smart cities. Hearing-impaired people, however, say that current technologies are still far in achieving integration; they have little or no access to a variety of daily routines and information as compared to normal people [13]. These limitations need to be removed to ensure that people with special needs have access to information which they can benefit from in order to interact with their immediate environment. Bouzid et al. [6] highlighted the need for identification of all barriers that reduces the life quality of people with special needs in urban areas and develop solutions that will allow future cities to accommodate these individuals without challenges. Research shows that the number of people with special needs is increasing due to a myriad of reasons including genetic causes, birth complications, exposure to high levels of noise, chronic infections among others [13]. Given that an estimated 66% of the population worldwide will be living in cities by 2050, according to the United Nations [3], smart cities will have an even greater number of people living with disabilities than the current numbers. A study by Diaz et al. [13] found that efforts for inclusion of people with disabilities using AR technologies have been slow although there are signs of positive progress. For this reason, developers need to improve the approach to create applications that serve the needs of people with special needs. Several innovative ideas for deaf and blind people have been put to reality using AR, such as a futuristic application with the capability of converting visual images into sound for blind people [17]. An application for converting speech to readable text superimposed on the physical environment of the deaf user also exists [27]. While most of these applications for deaf and blind individuals are novel, they set the correct model for developers to invest in applications that contribute to equity within the physical environment. Without these applications, people with disabilities will have difficulties interacting in urban areas where overcrowded places and most daily activities ignore the needs of individuals with disabilities. Notably, further research is necessary to enhance the capabilities of current applications to make them simpler and more effective for people with disabilities. Despite the apparent benefits of AR technologies in various aspects of smart cities, the level of attention that each of the three categories of mobility, quality of living and the environment attract from researchers and developers varies as shown by the available articles and research work. The study noted that environmental issues receive the highest attention at 60%, followed by living at 36% and finally, mobility at 19% [19]. The underlying issue for the differences in research attention lies with the increasing problems in most urban areas and the design of various applications suitable for each of the different aspects. Global warming and pollution receive the most media attention through the concerted efforts of various stakeholders to reduce the amount of harmful gas emissions to the atmosphere [44]. The costs and time investments in developing different applications often limit developers and the researchers' abilities to come up with applications that serve the needs of urban populations. Private organisations thus provide funding to developers and researchers to come up with ways of air pollution levels in urban areas. While mobility is also a major problem in urban areas, it is mainly up to the governments and local authorities to come up with solutions for congestion problems. Due to budget limitations, however, investment of funds into research is limited resulting in the low number of articles and applications focusing on mobility. In essence, a considerable amount of financial investment is necessary to speed up research and development of AR technologies for smart cities. Notably, several human aspects impede the speedy adaptation and utilisation of AR technologies for mobile phones in urban areas. Research into human behaviour that hinder the development of smart cities found that the lack of interest to apply technology to modern challenges, awareness over the possibility of surveillance, and self-sufficing attitudes towards technology are the main barriers [23]. While most people city dwellers today own smartphones, they prefer using them for their basic functions and fun as opposed to enhancing their experiences in a technological environment. This finding is an attribute of human nature to resist change, preferring to use all methods when dealing with new challenges. A suggestion was a forced approach in changing the attitudes of residents towards technology. Awareness over the possibility of government surveillance also emerged as an issue of concern for the population, hence the hesitation to completely rely on technology [23]. These concerns are preferred by most governments to achieve the highest level of control over its population. The problem of privacy breach is one that technology companies must address to prevent the unintended use of AR technologies for surveillance in cities. Markedly, the success of smart cities relies on the ability of its residents to adopt the use of technology in their daily activities.

3.3 Pollution and Climate Change Awareness Using AR

Rapidly growing city populations and an increase in human activities mean that emissions of harmful gases to the environment will go up. Furthermore, city dwellers expect cleaner environments and better livelihoods despite the challenges of pollution and various studies support the understanding that a more decent city has the potential for greater success due to their ability to attract more investment, tourists, and other support systems for businesses [19, 33]. However, several obstacles hinder the efforts to provide clean and desirable environments for investors. The importance of industrialisation means that pollution levels are high in most cities around the globe. Furthermore, the manufacturing and processing industries provide employment for thousands of people and significant interference with their activities can have negative effects on urban economies. A step by step shift towards socially responsible manufacturing promises great efforts to restrict the effects of pollution and global warming. Currently, environmental awareness methods are gaining importance due to the combined efforts of environmental activists, corporations, and governments to reduce the effects of global warming. Achieving the goal for clean cities, however, requires remote monitoring of air quality at various locations to determine the best approaches for providing clean environments to residents. Recent literature on personal monitoring of environmental aspects like air pollution, level of noise in enclosed environments, and atmospheric conditions highlight the use of portable devices to give real-time data about various parameters [33]. Efforts to develop smart cities that provide the best air quality for residents focus on projects that utilise remote sensors that collect data on various environmental parameters. The sensors are distributed at various locations within the city to collect and compute data that then gives precise information about the quality of air at specific locations [33]. These innovations overcome the challenge of static systems that can only measure air quality at a single location. Researchers, therefore, have to collect samples from various other locations to develop a profile of air pollution levels within the city. More precise and quick measuring of air quality at various locations in a city is achievable with sensors that collect data and send it to a central point for processing. Pokrić et al. presented the ekoNet system that utilises affordable sensors to measure the concentration of harmful gases like CO_2 and O_3 and transmit the data via a wireless network to the stations. The sensors were placed in public transport buses since they access various locations within the city. Unlike in others where sensors collect and compute the data, which is then displayed to the others, the innovation allows for faster computations while keeping cost at a minimum [33]. The ekoNet system thus allows for uniformity in measurements since defaults in one device can provide wrongful information to the user without their knowledge. The system, however, is less effective in environments with rapidly changing environmental parameters since it collects data at intervals. Its affordability, however, allows for deployments by authorities as well as private businesses. Stimulating city dwellers to engage in matters of environmental awareness is a fundamental approach in the process of creating awareness about pollution. Gamers using mobile phones can access information about the level of pollution from data collected by various sensors across the city. The mobile application uses data provided by the ekoNET system, which has sensors in various locations across the city [32]. When put into perspective, the citizen awareness system is built around the fast developing concept of the Internet of Things (IoT). The Internet of Things is a vast interconnection of appliances, sensors, and computers that allows the sharing of data and processing to provide information that enhances performance [47]. The data is transmitted to the gaming applications on smartphones hence enabling the gamer to experience the conditions as in the real world. The described approach allows for innovative and entertaining awareness efforts towards air pollution and global warming. The downside of most air quality systems in cities is their inability to provide individuals with specific data about their immediate space, either indoor or outdoor [14]. Governments and other relevant authorities usually experience high costs when building air quality measuring stations hence their limited number across many cities. As such, the effect of poor quality air is only accessible on a large-scale. Very few people pay attention to such information which leads to hindering efforts to increase awareness on the effects of pollution. Kaji et al. [19] stated that personal vehicles are a major contributor to the pollution problem in major cities. Emissions like CO_2 and smoke particles from the cars contribute to the poor quality of air. Therefore, awareness over the role of cars in increasing pollution can significantly impact efforts to reduce pollution. Providing pollution information at an individual level can enhance environmental understanding and contribute to smart cities. Dutta et al. [14] proposed an air monitoring system that could avail of pollution information to individuals using their smartphones. The user's smartphone is fitted with the air quality sensor that collects data about the quality of air. The sensors not only detect levels of gases such as CO_2 and NO_2 but also collect data on smoke and dust particles present in the air. The application on the phone connects to a cloud-computing service where the data is processed and presented on the phone screen for the user.

Typically, the data collection process and interpretation do not involve the input of the user hence making the app more comfortable to use. The user can also share the information with others within their surroundings. The concept of the Airsense system is supported by others used in air quality monitoring systems to provide precise information according to the immediate environment of the citizen [32]. The concept of personal awareness is useful in increasing awareness of air quality and the contribution of personal cars to the poor quality of air in cities. Initiatives to improve air quality require a large amount of awareness on pollution that current methods have been unable to achieve. An estimated 91% of the world population lives in areas where the quality of air is reduced, leading to diseases and other conditions that can be prevented or reduced [34]. Most of the applications available used to gather information on air quality ignore the critical aspect of education to create awareness. Furthermore, most of the mobile applications do not offer platforms for users to provide feedback on methods to improve air quality [34]. Most of the current strategies for controlling pollution are contributed by policy-makers, researchers, and environmental activists and mobile applications can play a critical role in the formulation of policies and strategies to restrict the effects of pollution [32]. However, feedback is also necessary to determine the level of awareness and adaptation of strategies to reduce pollution by the population. Allowing users to design actions aimed at reducing pollution improves awareness and can influence answers to support strategies to improve the quality of air in urban areas. Ramachandran et al. describe a mobile application, USC AiR that allows users to view air quality improvement strategies and make their contributions. Sensors were set up at strategic locations within the campus such that the smartphone would indicate when the user was in close proximity to the sensor. The user would then snap a photo of the immediate surrounding and access information about the various characteristics of the air. The interactive phase allows the user to make modifications to the surroundings, such as planting trees to improve the quality of air. The next user who utilises the sensor data will see modifications data by previous users [34]. Furthermore, USC AiR application allows users to post the modified picture to social media to increase pollution awareness. This innovative technology harnesses the power of social media to raise awareness further and contribute to the campaign for cleaner cities. Awareness approaches that allow users to visualise pollutants in their environment and their effects can significantly impact attitudes towards pollution. Torres [45] proposed that presenting both solid and gaseous pollutants in the form that the user would likely see them with the naked eye helps in enhancing the understanding that pollution is real and harmful to people. Microscopic pollutants that are invisible to the human eye are modelled into the Aire application for mobile phones. Their sizes are, however, exaggerated in the form of animations. The application then superimposes this virtual view to the physical world of the user. As the pollutants move through the physical world as seen on the phone screen, the user develops a realistic perception of their environment and how the pollutants affect them.

3.4 Augmented Reality in Traffic

As drivers become increasingly aware of the benefits of technology in improving safety while driving, there has been a high reception of technologies utilising AR to connect the driver to the environment. Abdi et al. [1] argued that the Head-Up Display that incorporates AR (AR-HUD) are the future of driving. The researchers noted that a lot of previous solutions concentrated on acquiring a lot of data about the vehicle and traffic without putting it into effective use. These assertions are supported by findings by Kim et al. [22] that collision warning utilised in most vehicles provide warnings without pinpointing to the driver where the pedestrian is located. Without knowledge of the position of the pedestrian, the driver still risks accidents despite the warning. AR-HUD can significantly improve the way drivers respond to warnings without interfering with the driver's attention [1]. Drivers sometimes get overwhelmed by situations where they have to make multiple and fast decisions, thus increasing the risk for errors. AR-HUD provides real-time information to the driver about the environment together with cue on how to navigate the situations. Information about safe distances to other vehicles and pedestrians, warning for collisions [41], and their direction can help in overcoming the human challenge of distraction and overload of information during driving. Poor visibility is a significant cause of accidents, as highlighted by the high number of injuries and deaths to pedestrians. An estimated 76,000 injuries and 4700 fatalities to pedestrians occurred in 2012 alone in the USA. Issues of poor driver visibility, slow reaction, poor crossing, and human errors were the underlying causes of the accidents. The researcher proposed an ecological interface design that incorporates AR to help drivers to actively interact with their environment react more quickly to dangerous situations [22]. The challenge in designing the system was to differentiate between pedestrians who were standing to let the vehicle through and those that were likely to get hit. The application was designed to provide only cues about pedestrians that were likely to interfere with the path of the vehicle. Shadow markers were, however, applied to provide the right cue without distracting the driver. In-vehicle AR-HUD systems show promise in improving safety standards, especially in congested cities. As cities strive to move towards smart cars, attention towards mobile applications utilising AR for traffic prediction remains limited. The practical applications of an AR system for predicting traffic was proposed by Rameau et al. [35]. The system is designed such that a large vehicle such as a truck of bus has a camera on its front wind shield that captures the view in from and transmits to the rear vehicle whole diver cannot see the stretch of road. The image relayed to the LED screen of the rear vehicle is such that the driver sees the virtual way without the obstructing vehicle; hence is capable of making decisions depending on the traffic ahead. Developers, however, encountered problems with the transmission of the image, which was fractions of milliseconds late [35]. The delay is significant since it can make an oncoming vehicle appear farther than its actual distance, thus posing significant risks to motorists. Notably, research into road traffic prediction systems is still in its infant stages. More resources need to be invested in developing AR traffic systems that allow drivers to get instantaneous information about traffic flow.

3.5 Awareness

Several studies in air quality in urban areas outline the current weaknesses in accessing information about pollution pinpointed to the specific location of the user [33]. Proposed solutions aim to improve the accessibility of this information by providing sensors either on the user's phone or the several strategic locations for collecting environmental parameters [14, 19]. Furthermore, awareness efforts towards pollution in cities involve the utilisation of applications that allow for remote sending of data on environmental parameters in real-time [33]. Therefore, there is a requirement for the population to become more aware of the negative effects of pollution. This can be achieved with current technology, such as AR in order to enhance a cleaner environment.

4
Solution

This chapter discusses the proposed solution for the problems stated in Chapter 1. where the awareness of the population will be investigated. A website prototype which includes immersive AR to visualises air pollution is introduced. Additionally, an interactive page allows the user to address certain issues in the city and leave feedback for other users. Finaly, we discuss the designed prototype.

4.1 Web Application

In contrast to native mobile applications which are created for specific platforms, we designed a responsive website that can be accessed by using the web browser regardless of the operating system. The website can be accessed depending on the compatibility of the device which is decided on whether the device is supported by ARCore or ARkit. We also us the opportunity to investigate the WebXR API since it is an upcoming trend in creating VR and AR applications for the web. In order to integrate AR in websites, libraries such as AR.js which utilises markers or the WebXR API that uses positional tracking can be used. The designed prototype utilises the WebXR API to create a scene without the use of markers. Utilising markers is an infeasible task as they will need to be placed all over the city.

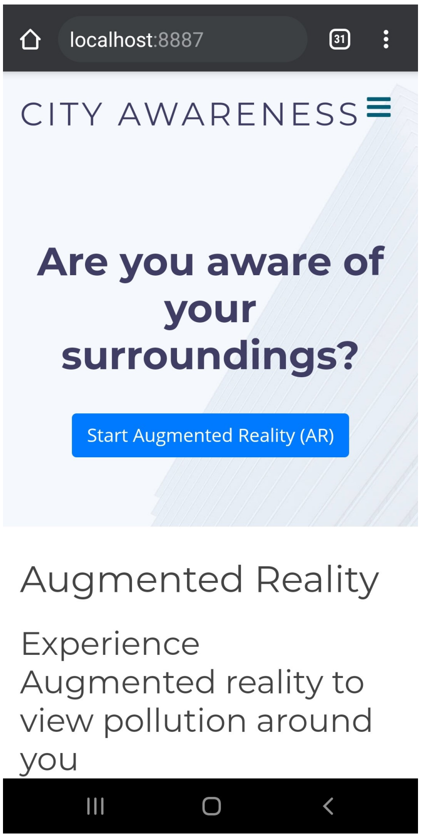

Figure 4.1: Starpage

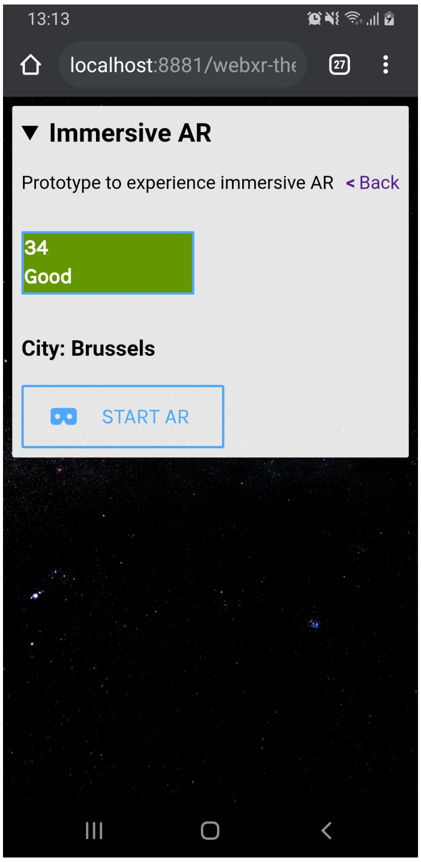

Figure 4.2: Start AR screen

The first screen in Figure 4.1 of the prototype shows the homepage of the simple website. The button 'Start Augmented Reality' will redirect the user to another screen where the geolocation of the user's device is acquired to extract air pollution data. This data will be visualised in immersive AR when the 'START AR' button in Figure 4.2 is clicked. Once the button is clicked the user will see the environment with the 3D models provided to visualize the air quality as shown in Figure 4.4 . Additionally, the user can leave feedback for others where they discusses topics concerning aspects of the urban environment.

Notice the number 34 followed by the text "Good" that is displayed within the green box. This is the air quality index to summarize the air quality and the health issue it comes with. We followed the same structure of acqin and simplified the range of values.

These are the values that determine the colour and text based on the index from the API call.

- values < 50 are good and are displayed in a green box
- values ≥ 50 and < 100 are moderate and are displayed in an orange box
- values ≥ 100 are unhealthy and are displayed in a red box

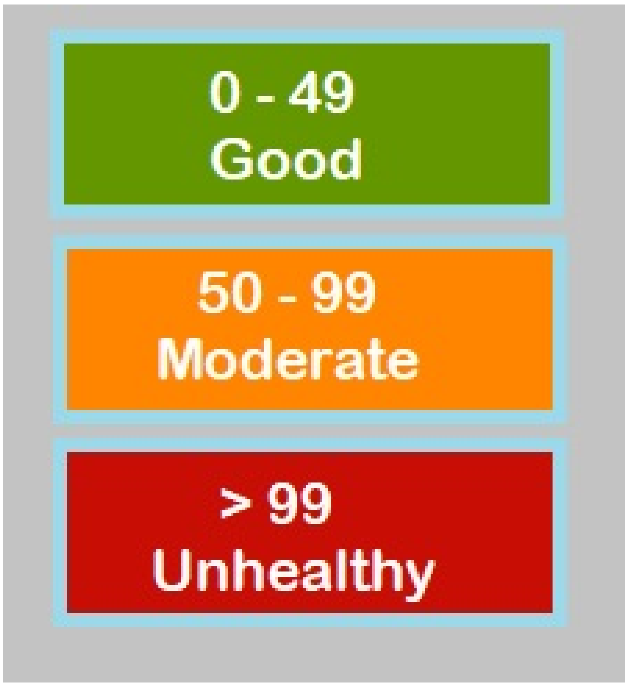

Figure 4.3: Colour indication for the air quality index

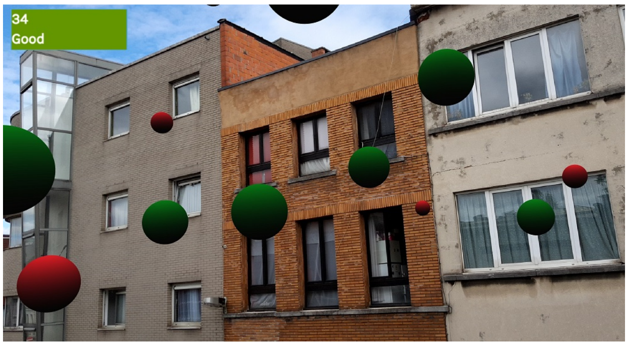

Figure 4.4: Immersive AR view with red and green spheres

5
Implementation

This chapter discusses the implementation of the prototype web application and the software that was used in this project. Given the early stages of WebXR, the first challenge was to experiment with the API and to try various tools to run an example. We used sample code[1] that adds a scene utilising WebXR to which we added extra code to experiment with the API and for the website we used a free-css template[2] which we modified to achieve the desired outcome.

5.1 Web Application

As discussed in Chapter4 the implementation utilises the WebXR API to integrate AR in the browser. AR requires rendering of scenes and objects which are then added to the screen. Alongside WebXR, the sample code also includes WebGL API to render the 3D objects and add them to a scene. The 3D that are shown on the screen are simple spherical objects that were created in blender[3] where the colours green and red determine respectively good or bad air quality. The data to determine the air quality is retrieved

[1] https://immersive-web.github.io/webxr-samples/
[2] https://www.free-css.com/free-css-templates
[3] https://www.blender.org/features/

via API call as illustrated in Figure 5.1. The data is freely accessible via API calls where either the location name is sent in the header of the call or via coordinates. The geolocation must be enabled in order to get the coordinates of the mobile device. These coordinates are used to locate the user and request air quality data from aqicn API.

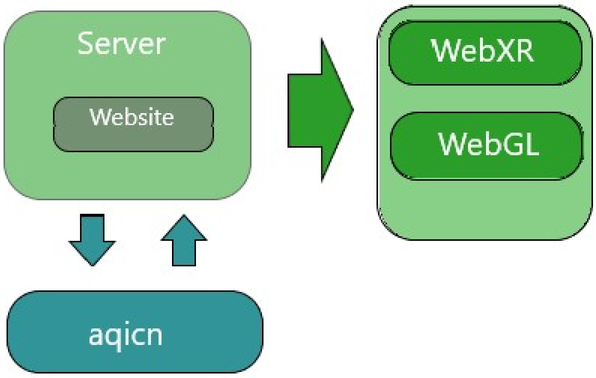

Figure 5.1: Architecture of the implementation

5.2 Air Quality API

Some cities are equipped with sensors to collect any type of data in their environment. Some of the data is freely accessible and provided via an API. This also applies to data for air quality which is retrieved from an API for this Thesis. One of the more complete and easy to access API's which is also used in our prototype was aqicn API[4]. The API provides access to a collection of information that has been acquired via sensors located in cities from all over the world. One can either call the data by providing a city name or the current geolocation of the user's device. When a request has ben sent to the server, the API will send a response in JSON format where the necessary data can be extracted from. Before the implementation of any API logic we tested the API with Postman[5]. Postman is a third party tool that provides a way of testing and developing API. Each call requires a unique token that needs to be generated on the website of aqicn[6]. This token is included in the

[4]https://aqicn.org/api/
[5]https://www.postman.com/
[6]https://aqicn.org/api/

header and with each call. Additionally, some extra information is needed to request specific data which in this case is the location of the user.


```
"status": "ok",
 "data": {"aqi": 21,"idx": 8906,"city": {
 "geo": [51.2056589, 4.4180728],
 "name": "Antwerpen (belgi&euml;lei), Belgium",
 "url": "https://aqicn.org/city/belgium/fla/antwerpen-belgi-euml-lei"
 }
```


5.3 Geolocation

The location is crucial to retrieve the correct data from the API. Either by typing the name of the city or by sending the current location a user will get the correct air quality index information. Since most devices are equipped with GPS sensors, the option to send coordinates to the API was preferred. The geolocation is first determined and this is sent in the header of the api call. The response is the JSON format specified in Section 5.2.

5.4 Blender

Our models as shown in Figure 5.2 are simple spheres that where designed with Blender[7]. We created a sphere representing air and added a color to represent the quality. These models are a measure of comparing the good air in relation to bad air. They do not indicate the exact position nor the amount of molecues in the air.

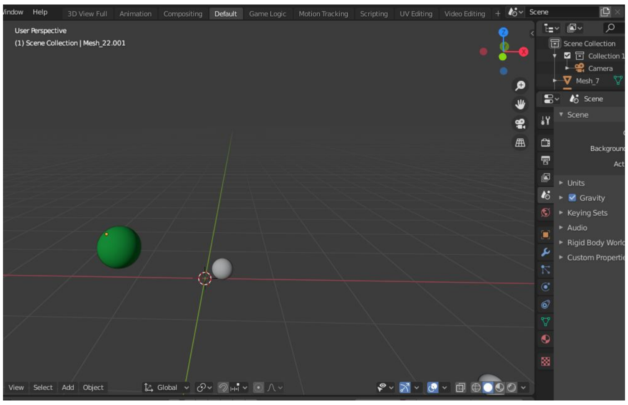

Figure 5.2: 3D object created in Blender

[7] https://www.blender.org/features/

5.5 Hosting

The server is a separate tool that is used to host the sample code on a local machine. Web Server for Chrome as shown in Figure 5.3 is used to set up a local server to host the website. Additionally, portforwarding was enabled to allow mobile devices to access localhost for immersive AR experience. Web Server for Chrome is an easy to use tool and was used in combination with Canary chrome browser during development and testing.

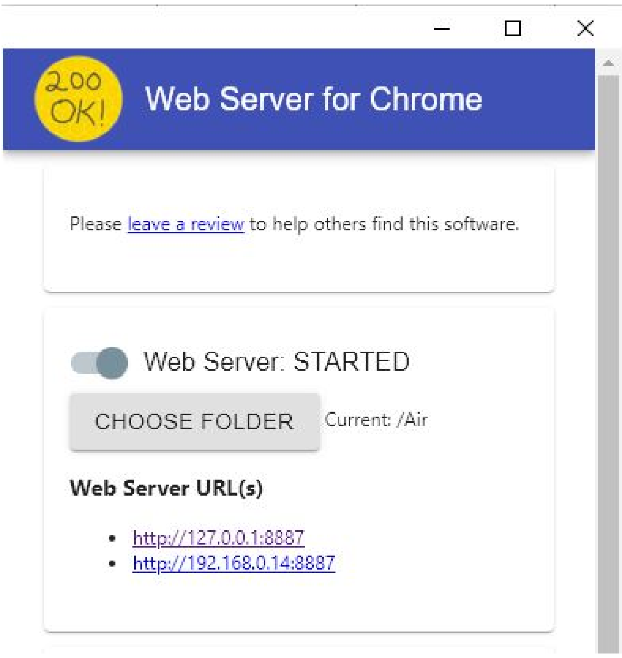

Figure 5.3: Web Server for Chrome used to host locally

6 Evaluation

This chapter discusses the evaluation on the concept of user awareness combined with AR which has been discussed in the previous chapters together with the prototype that we provided. We evaluated the results with a short version of the User Experience Questionnaire (UEQ)[1]. The user's experience and awareness was measured with this questionnaire in which 7 people, 2 females and 5 males, participated. The individuals used their smartphones to test the web application. Additionally, some feedback was requested for further improvements.

The individuals were split into two groups and the tests was divided into two parts. In the first part, we asked the individuals a few questions about their awareness of the urban environment. Subsequently, the first group, consisting of 3 people, started by testing our web application while the second group was provided with instructions to find the air quality index on the internet. After the first test, the roles of both groups were switched. We provided the first group with instruction to find data online while the second group used our web application for an AR experience.

The users where also given a questionnaire after the test to gather information on the added value of AR. The questionnaire starts with a general review of the small prototype web application. Subsequently, some additional questions about stimulation and the concept of using AR as an added value

[1] https://www.ueq-online.org/

were asked. Below are the questions concerning the prototype. We followed the standards of this questionnaire which leads us to evaluate the pragmatic and the hedonic quality.

- Is a clean environment important?
  - not important - 1|2|3|4|5|6|7 - very important
- Are you aware of the air quality in your environment
  - not at all - 1|2|3|4|5|6|7 - very aware
- What are the general impressions about the application?
  - 1: obstructive - 1|2|3|4|5|6|7 - supportive
  - 2: complicated - 1|2|3|4|5|6|7 - easy
  - 3: inefficient - 1|2|3|4|5|6|7 - efficient
  - 4: confusing - 1|2|3|4|5|6|7 - clear
  - 5: boring - 1|2|3|4|5|6|7 - exiting
  - 6: not interesting - 1|2|3|4|5|6|7 - interesting
  - 7: conventional - 1|2|3|4|5|6|7 - inventive
  - 8: usual - 1|2|3|4|5|6|7 - leading edge
- Do you have additional recommendations?
- Is the data displayed clearly?
  - confusing - 1|2|3|4|5|6|7 - clear
- Do you have additional recommendations on the data?
- Does augmented reality provide a pleasant experience?
  - unpleasant - 1|2|3|4|5|6|7 - pleasant
- Would you recommend AR for data visualisation?
  - disagree - 1|2|3|4|5|6|7 - agree
- Would you recommend looking up information online?
  - disagree - 1|2|3|4|5|6|7 - agree
- Do you have additional feedback on augmented reality?

6.1 Result

We used the Short UEQ Data Analysis tool[2] to evaluate the results from the questionnaire. According to the Short UEQ tool the values can be interpreted as values between intervals. The range of the scale is between -3 (bad) and +3 (good). The mean value between -0.8 and 0.8 represents a neutral evaluation on the corresponding scale, values between 0.8 and 3 represent a positive evaluation and the values between -0.8 and -3 represent a negative evaluation.

Item	Mean	Variance	Std. Dev.	No.	Negative	Positive	Scale
1	0,7	0,9	1,0	7	obstructive	supportive	Pragmatic Quality
2	2,3	0,2	0,5	7	complicated	easy	Pragmatic Quality
3	0,6	0,6	0,8	7	inefficient	efficient	Pragmatic Quality
4	1,0	1,0	1,0	7	confusing	clear	Pragmatic Quality
5	1,0	0,7	0,8	7	boring	exciting	Hedonic Quality
6	1,3	0,9	1,0	7	not interesting	interesting	Hedonic Quality
7	2,0	0,7	0,8	7	conventional	inventive	Hedonic Quality
8	1,9	1,1	1,1	7	usual	leading edge	Hedonic Quality

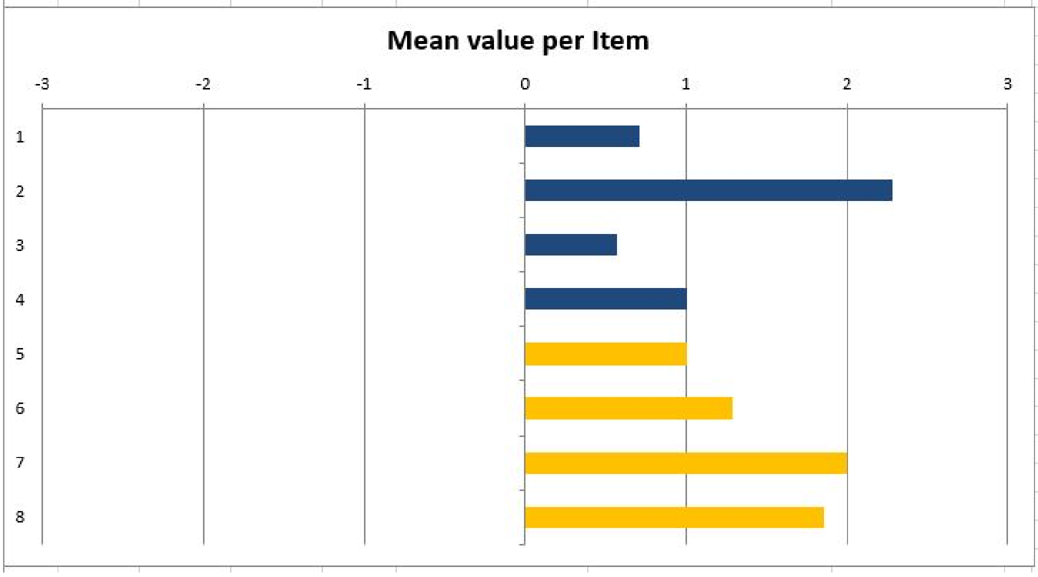

Figure 6.1: Plot for the mean value per item, UEQ

The evaluation of the plot in Figure 6.1 shows a low mean average on the pragmatic quality for points 1 and 2. The participants evaluated all the other aspects positively. Figure 6.2 shows us that the overall average result is positive. Two of the participants experienced AR as playful which

[2]https://www.ueq-online.org/

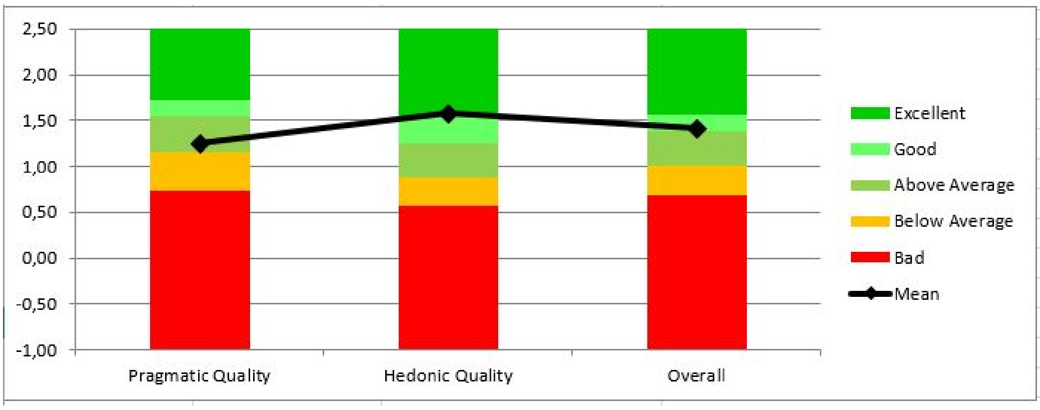

Figure 6.2: Plot for the average bencmark, UEQ

would encourage them to check the web application more often. Based on the questionnaire and the feedback of the participants, we found out that the participants are pleased with experiencing immersive AR and see this as an added value to increase awareness. However, there might be a need for push notifications to remind the user to check regularly.

7

Future Work and Conclusion

7.1 Future Work

The website that we have provided was simple and easy to use. This was done with respect to user-friendliness. We were able to create the prototype by using the WebXR API and geolocation to retrieve data. However, the first point that could be further investigated is the data for the Air quality index. The data is acquired from the closest measuring location. The result of the quality index is displayed for the locations that are the nearest to a specific measuring unit. According to our findings, when a user is located between two sensors in the city they will receive data from only one of the two point. This data could be more specific when we would acquire information from more measuring units in the same city and use interpolation to fill in the voids which would create an interpolated result of information between two measuring points. Hence, providing a flow of data that is calculated based on multiple input.

Furthermore, an option to compare between cities is in which users would observe whether the current city they are located in is doing a better job when it comes to environment contribution. A healthy environment is more pleasant to live in and the comparison could also help in the decision of whether one wants to move or not. Additionally, this comparison can also be done within the city itself. A 2D map overlaid with colours will display areas in the city with different colours to show cleaner areas. These information could be used to decide where users want to rent or buy a house. Finally, more information will need to be provided to the user that explains the data more extensively. For example, more detailed information about polluted areas and the type of pollutant that are present in the air.

7.2 Conclusion

Firstly, we would like to note that this thesis was conducted during the difficult times with confinement measures due to Covid-19. This had an impact on our development and the way we could evaluate the prototype.

In this research, we stated the problems in Section 1.1 to highlight issues on user awareness in the urban environment such as air quality. This gave us the opportunity to address this issue by utilising new technologies in order to stimulate the user's awareness of their surrounding. Since 'surrounding' is a general term which can be any location that is physically accessible, we proposed a solution to experience augmented reality which is not limited to a single place or marker. We described our prototype web application which uses WebXR and WebGL. WebXR proved to be a challenge with limited documentation since it is an upcoming trend of AR and VR application design for websites.

In order to successfully attain our goal, we investigated the possibility to use augmented reality with current methods and devices to create a web application. This led to a comparison between different tools and devices. Additionally, Chapter 3 contains related work that shows the rising interest of augmented reality and its use in smart cities. Based on this investigation, we designed and developed a prototype that uses the WebXR API to create scenes and WebGL for rendering. With the help of WebXR, users will be allowed to experience immersive AR with any compatible device without utilising a marker. Furthermore, they can give suggestions or feedback on any topic that occurs in the urban environment. Finally, in order to achieve the goal of the research we conducted a limited survey due to the Covid-19 health measures. We were able to create a prototype that is accessible by any compatible device via browser and the survey showed that the use of augmented reality is enjoyable and that users are more inclined to learn when interactive visualisation is involved. They enjoyed the way data is visualised and with the feedback of the survey we also found points for improvement.

A
Your Appendix

A.1 Data Retrieval

```
var latitude = '';
var longitude = '';

var element = document.getElementById('data');
var element2 = document.getElementById('data2');
var node = document.createElement('h2');
var node2 = document.createElement('h3')

function getPosition() {
if (navigator.geolocation) {
navigator.geolocation.getCurrentPosition(showCoordinates);
getRequest();
} else {
element.innerHTML = 'Geolocation␣is␣not␣supported␣by␣this␣browser.';
}
}
function showCoordinates(position) {
latitude = position.coords.latitude;
longitude = position.coords.longitude;
}

function getRequest() {
return fetch('https://api.waqi.info/feed/geo:'+latitude+';'+longitude+'/?
    token=c98904dbaebe5ac28f5b955866228695ff04ad3f' )
.then((x) => x.json()).then((obj) => {
if (obj.status != 'ok') throw obj.reason;
if (obj.data.aqi < 50) {
health = 'Good';
```

```
color = 'green';
}
else if (obj.data.aqi < 100) {
health = 'moderate';
color = 'orange';
}
else {
health = 'unhealthy';
color = 'red';
}
node.className = 'aq-box ' + color;
node.innerHTML = obj.data.aqi  + '\<br>' + health;
node2.innerHTML = 'City: ' + obj.data.city.name;
element.appendChild(node);
element2.appendChild(node2);
});
}
```

A.2 API Response


```
{
"status": "ok",
"data": {
"aqi": 21,
"idx": 8906,
"attributions": [
{
"url": "https://www.irceline.be/en/",
"name": "IRCEL-CELINE - Belgian Interregional Environment Agency",
"logo": "Beligium-irceline.png"
},
{
"url": "https://waqi.info/",
"name": "World Air Quality Index Project"
}
],
"city": {
"geo": [
51.2056589,
4.4180728
],
"name": "Antwerpen (belgi&euml;lei), Belgium",
"url": "https://aqicn.org/city/belgium/fla/antwerpen-belgi-euml-lei"
},
"dominentpol": "pm25",
"iaqi": {
"h": {
"v": 50.8
},
"no2": {
"v": 8.7
},
"p": {
"v": 1008.6
},
"pm10": {
"v": 17
},
```

```
"pm25": {
"v": 21
},
"t": {
"v": 26.8
},
"w": {
"v": 9.6
},
"wg": {
"v": 17.6
}
},
"time": {
"s": "2020-08-21 12:00:00",
"tz": "+02:00",
"v": 1598011200,
"iso": "2020-08-21T12:00:00+02:00"
},
"forecast": {},
"debug": {
"sync": "2020-08-21T19:22:44+09:00"
}
}
}
```

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