MAURITIUS RESEARCH COUNCIL

TOWARDS GREEN CONSUMPTION OF ELECTRONIC DEVICES: USING AUGMENTED REALITY TO IMPROVE AWARENESS

Final Report

November 2016

MAURITIUS RESEARCH COUNCIL

Address:

Level 6, Ebène Heights,
34, Cybercity,
Ebène 72201,
Mauritius.

Telephone: (230) 465 1235
Fax: (230) 465 1239
Email: mrc@intnet.mu
Website: www.mrc.org.mu

This report is based on work supported by the Mauritius Research Council under award number MRC/RSS-1506. Any opinions, findings, recommendations and conclusions expressed herein are the author's and do not necessarily reflect those of the Council.

Towards Green Consumption of Electronic Devices:

Using Augmented Reality to Improve Awareness

Final Report

Date: November 2016

A Research Report By:

1. Mr. Girish Bekaroo (Principal Investigator)
Middlesex University (Mauritius Branch Campus)

2. Dr. Priscilla Ramsamy (Co-Investigator)
Middlesex University (Mauritius Branch Campus)

3. Mr. Roopesh Kevin Sungkur (Co-Investigator)
University of Mauritius

4. Mr. Alexander Okolo (Co-Investigator)
Middlesex University (Mauritius Branch Campus)

5. Ms. Waseemah Moedeen (Research Assistant)
Middlesex University (Mauritius Branch Campus)

Executive Summary

Over the last few decades, the adoption of innovative technologies in both households and businesses has brought immense benefits to human beings, such as increased productivity, improved entertainment and communication, and much more. Both developed and developing countries are making significant efforts to promote the adoption of technological devices so as to achieve economic growth and development, improved public health and standard of living. However, the increasing use of these technologies has also resulted in the deterioration of the relationship between technology and the natural environment. The growing number of electrical and electronic devices present in both homes and offices are contributing to the continuous increase in energy consumption both in Mauritius and throughout the world. The generation of electricity is known to be a key cause of climate change due to the use of non-renewable sources such as coal and oil which release carbon dioxide and other pollutants into the atmosphere. The growth of electronic devices has also resulted in an increase of electronic waste, which is also detrimental to the human health and the environment. As such, in order to mitigate the global climate change problems being faced, it has become important for human beings to take actions to reduce the risks and damages to the environment also caused by electronic devices.

One possible solution is to use ICT based mitigation techniques to help human beings reduce their environmental impacts during the use of electronic devices. Studies have showed that a lack of knowledge is often considered as a key barrier to the adoption of environmentally sustainable actions. One emerging technology that has shown to foster engagement, improve understanding and provide a unique learning experience is Augmented Reality. This study aims to assess the effectiveness of using Augmented Reality to improve awareness on green consumption of electronic devices. To achieve this, an Augmented Reality mobile application was developed to help individuals learn and understand their electricity consumption from various electrical devices being used at home and offices. The application also provides a means for end users to track the amount of energy consumed by different devices, and provided appropriate tips and best practices to educate users on green practices. Additionally, the application also contained a quiz feature to assess the knowledge of the users. Following evaluation, results confirmed the hypothesis of the research project and indicated a positive correlation between Augmented Reality and learning enhancement on green practices. This was denoted by an improvement of 39.8% in test results conducted after utilization of the implemented prototype.

Acknowledgement

Special thanks and appreciation to the Mauritius Research Council for the financial assistance provided, without which this research study would not have been possible.

The successful completion of the research project would not have been possible without the immense support of Middlesex University (Mauritius Branch Campus), and many thanks also to the University of Mauritius for providing appropriate guidance throughout the study.

Thanks also to the Research Assistant, Ms Waseemah Moedeen who has contributed towards the realization of this project.

Finally, a special gratefulness is conveyed to all students and staff members of Middlesex University (Mauritius Branch Campus) who have participated in the study and also all stakeholders for their instrumental assistance.

Table of Content

List of Figures

List of Tables

List of Acronyms

Acronym	Description
AR	Augmented Reality
GPS	Global Positioning System
KWh	Kilowatt per Hour
CO_2	Carbon Dioxide
OECD	Organisation for Economic Co-operation and Development
WEEE	Waste Electrical and Electronic Equipment
RoHS	Restriction of the Use of Certain Hazardous Substances
EuP	Energy using Products
LCA	Life Cycle Assessment

Chapter 1– Introduction

1.1 Project Overview

Since the last few decades, the world has entered an era of unprecedented digital disruption in the form of technological innovation and major evolutions in the ways people have adopted technologies within both businesses and households (Crosbie, 2008; Manyika, et al., 2013). This is because adoption of technology brought diverse benefits to human beings in the forms of improved productivity, entertainment and communication, among others. For both developed and developing countries, considerable efforts are being made to promote adoption of new technologies in order to achieve national goals such as economic growth and development, international commerce, improved public health and standard of living (Silberglitt, et al., 2006). Television sets, washing machines, computers and mobile phones are only a few among the list of electronic devices present within global households and business organisations today. However, as human beings became increasingly dependent on such devices, the relationship between technology and the natural environment continuously degraded (United Nations Environment Programme, 2015). The growing number of electrical devices present in homes is contributing considerably to the growth in energy consumption (U.S Energy Information Administration, 2011). The average energy consumed by electrical devices in a typical American household is between 1000-1200 KWh per year (California Energy Commission, 2008). According to Central Electricity Board (2013), electricity sales in Mauritius increased significantly from approximately from 1492 GWh in 2002 to around 2,160 GWh in 2011. Generation of electricity is known as a key cause of climate change due to the use of non-renewable sources (e.g. coal or oil) that releases carbon dioxide, pollutants and sulphur into the atmosphere (Murugesan, 2008). Furthermore, growth in the consumption of electronic devices also contributes to the growing e-waste problems, especially after the usage lifetime of these devices (Widmer, et al., 2005). E-waste is known to contain hazardous constituents which can harm both the environment and human health if not managed properly (Nnorom & Osibanjo, 2008; Bekaroo & Bokhoree, 2011). Taking cognizance of these problems and to mitigate the global climate change effects being faced, it has become mandatory for human beings to take early actions in order to reduce the risks, damages and associated impacts on the environment (Watson, et al., 1996; O'Neill & Oppenheimer, 2002).

One recognised solution to mitigate the above problems is to consume electronic devices in an environmentally sustainable or green manner (Shina, 2008). For this, end users need to be aware of the techniques and best practices available so as to be able to use their electronics in an environmentally sustainable way. ICT based solutions have greatly impacted the environment in a positive manner by helping to reduce greenhouse gas (GHG) emissions and by enhancing the way information is made available and presented to human beings, in order to further help in the knowledge acquisition and sharing process (Uddin & Rahman, 2012). To promote learning on green use of electronics, different tools including environmental web portals, blogs, wikis and interactive simulations of the environmental impact of an activity are presently available (Murugesan, 2008). However, even with the availability of these resources, recent studies in Mauritius showed that students at university level have moderate knowledge about environmental sustainability or energy efficient use of computing and electronic devices (Dookhitram, et al., 2012; Bekaroo, et al., 2012). The same studies also showed that it is students who form part of the highest number of users of these electronic devices. Furthermore, if such is the present situation for university students, worse could be expected from non-university students in terms of awareness.

Generally, knowledge has often been argued as a key barrier to the adoption and implementation of environmentally sustainable actions (Wabwoba, et al., 2012). Limited knowledge can considerably obstruct the implementation process of greener actions needed to benefit the environment (Othman, et al., 2011). Moreover, although personal engagement is often claimed to be of utmost importance when it comes to the implementation of environmentally sustainable techniques, this factor is considered to be limited among users (Mattern, et al., 2010). One emerging technology which is considered to have the potential to release trapped intelligence and to better engage learners is Augmented Reality (AR) (Dede, 2009; Wagner, et al., 2005).

Augmented Reality permits users to see the real world environment with virtual objects superimposed upon (Azuma, 1997). AR supplements reality by using computer generated input including graphics, sound, video or GPS (Global Positioning System) data. It has been used in the past to teach the Earth and Sun relationship to Geography students (Shelton & Hedley, 2002), to teach biology to secondary students (Ramsamy, et al., 2006) and to explain to undergraduate students about how different parts of a computer system could work in reality (Fernandes & Miranda, 2003). The same studies demonstrated an overall improvement in student understanding after use of this technology, besides engaging students.

1.2 Problem Definition

Although Mauritius has been projecting itself as a sustainable island with high initiatives undertaken by the Government towards going green, knowledge is still being considered as a barrier to the implementation of environmentally sustainable actions (Dookhitram, et al., 2012; Bekaroo, et al., 2012). Mauritian households and businesses are dependent on the growing number of electronic devices and need to be aware of the techniques and best practices available so as to use these devices in an environmentally sustainable way and help towards greening Mauritius. Since awareness is still being regarded as a barrier, it implies newer ways are needed so as to help overcome this barrier. One emerging technology that has shown to foster engagement, improve understanding and provide a unique learning experience is Augmented Reality (Pan, et al., 2006). Several studies have indicated that AR systems have benefited learners in a more effective way compared to other technology-enhanced learning environments (Sayed, et al., 2011; Mathews, 2010; Rosenbaum, et al., 2007). Even though this technology is emerging within educational systems, Augmented Reality has not yet been exploited to improve awareness on environmentally sustainable use of electronic devices. Despite efforts made on integrating AR in mobile gaming applications to promote green awareness and pro-environmental behaviours, little research has been done to assess the effectiveness of AR as a learning and sensitization tool for reducing personal energy consumption in both homes and offices (Kalz, et al., 2015; Sapountz & Oungrinis, 2015). This raises the following question: *Can Augmented Reality be effectively used as a mechanism to improve awareness on green utilisation of electronic devices?*

1.3 Aim and Objectives

The aim of this research study is to assess the effectiveness of using Augmented Reality to improve awareness on green consumption of electronic devices. Through the development of an AR application, individuals can learn and understand their electricity consumption from various electrical devices being used at home and offices, and the impact of these devices on the natural environment. The AR application also seeks to encourage individuals to adopt environmentally sustainable behaviours regarding electricity consumption, and thus contribute towards a greener Mauritius. The objectives of the project are outlined below:

- Establish a taxonomy for the utilization of electronic devices in an environmentally sustainable manner,
- To design and develop a prototype for improving awareness via augmented reality,
- Evaluate the extent of how Augmented Reality can improve the learning process on green consumption of electronic devices.

1.4 Key Contributions

This research study is expected to have different key contributions. The first one is a taxonomy of electrical and electronic appliances. In order to move towards green consumption of electronic devices, a list of the major electrical and electronic appliances needs to be set up and categorised into households and office appliances. This taxonomy will be investigated and adopted in this project. Furthermore, a mechanism to assess the environmental sustainability of the mobile application users will also be developed. This mechanism is mainly known as an energy assessment mechanism, whereby the users will have the possibility to keep track and attempt to reduce their energy consumption. Together with this mechanism, a prototype mobile application will be developed. This application will make use of the Augmented Reality technology to help users manage and reduce their electrical energy consumption. Users will be able to detect any electrical appliances being used and track their energy consumption using the AR prototype mobile application. Lastly, after developing the application, it will be evaluated with a set of participants to assess the hypothesis of the research project.

1.5 Summary of Chapters

The report started with an overview of the project to be developed, along with a description of the aims and objectives and some of the key contributions of the project. The following is a summary of the chapters in the report:

Chapter 2: The chapter starts with a discussion on the growth of electronic devices consumption and their effects on the natural environment. This is to be able to propose an effective solution to reduce the consumption of electronic devices. The first step was to identify the rise in electrical and electronic devices used in both household and offices and the resulting increase in electrical energy production both at the international and local level. This was followed by a critical analysis of the impact the rise in electrical energy due to higher electronics consumption has on the environment. The associated environmental concerns such as rising carbon emissions and electronic wastes were discussed in detail. Afterwards, the different measures taken by various stakeholders such as international organisations, governments and end-users to mitigate the environmental concerns associated with rising electronic devices consumptions were looked into. In order to be able to propose a useful and effective solution to the rising electronics consumption, the barriers linked to the prevention of electronic devices consumption were investigated. Different barriers were identified such as lack of knowledge and proper tools to aid in reducing personal electronics consumption. As such, Augmented Reality (AR) was proposed as an educational technology to help individuals track and reduce their personal electronics consumption. AR was selected as the most appropriate technology for electronics consumption reduction due to its effectiveness in self-learning and helping individuals track their electronics consumption in a more interactive environment. Different existing AR applications and tools which focused on green electronics consumption were critically reviewed so as to assess how effective those tools are in promoting green electronics consumption.

Chapter 3: In Chapter 3, a taxonomic study was conducted in order to determine the most common electronic appliances being used at homes and offices. This taxonomic study also highlighted the importance of green consumption of electronic devices. Different existing taxonomies were looked into in order to determine which was most suitable to use for this research project. The taxonomies comprised mainly of a list of all the main and most common electronic and electrical appliances used at homes and offices. At the end of the taxonomic study, one taxonomy was selected to be applied in the development of the AR application. The literature review phase concluded with a detailed list of the best practices to be followed for reducing personal electronics consumptions and the related environmental concerns.

Chapter 4: After the literature review, the next phase of the project was application design. The application design section firstly consisted of specifying the functional and non-functional requirements of the mobile AR application. This was followed by preparing wireframes of the application, that is, the different functions the application would contain and how the user interfaces will be like. The low-fidelity prototype was done using Balsamiq software. Afterwards, use case analysis was performed so as to represent the functional requirements of the application. Different use case diagrams were described. After use case analysis, class diagrams were prepared so as to give a static view of the application, and document the different aspects of the system. The last part of the application design phase was drawing the sequence diagrams to give dynamic representation of the application. The sequence diagrams helped in understanding how the different objects in the application interact with different classes in a particular time sequence. After the sequence diagrams were made, an entity-relation diagram was developed so as to further describe how the webserver database will be structured.

Chapter 5: When the design phases was completed, the next step was to start developing the application. The required software and plugins were installed and the development environment was set up. An account was created on Vuforia developer portal to create and update the AR targets database. The different menus were created. A list of electrical and electronic appliances to be tracked was finalised and respective images representing the appliances was compiled. The images were converted into image targets via Vuforia Target Manager. After all the required functionalities were developed, the next phase was to test the functional and non-functional requirements of the application. This was done during and after implementation.

Chapter 6: Chapter 6 focuses on the next step of the project which was to start the user evaluation of the mobile application. The evaluation approach is described in detail in the evaluation chapter. To meet the last objective of the research, a pre-test and post-test design approach was chosen. The application was then evaluated with 40 participants, half were students and the other half were staff members of Middlesex University Mauritius Branch Campus. The participants were asked to use the application for one week and were then given the evaluation questionnaires to fill in. After the participants had completed the evaluation, the data obtained were then analysed.

Chapter 7: Chapter 7 consists of a description and analysis obtained from the user evaluation conducted. The data gathered from the pre-test and post-test evaluations were analysed using SPSS software. The results were represented mainly through graphs and comparisons were made between results from the pre-test questionnaires and the post-test questionnaires. As per the objective of the research study, an analysis was done to determine whether Augmented Reality can enhance the learning process on green consumption of electronic devices.

Chapter 8: In the last chapter of the report, a summary of the research project was done. The different limitations encountered throughout the research study were discussed as well, and the chapter end with a description of the future works which can be achieved through the findings from this project.

Chapter 2– Literature Review

2.1 The Growth of Consumption in Electronics

There has been a dramatic rise in the electricity and electronic consumption in both households and businesses in the recent years (International Energy Agency , 2014). It has been found that with increasing income, expanding middle-class population and increased internet penetration, the consumer electronics market became more robust during the year 2015 and is expected to continue growing afterwards (Future Market Insights, 2015).

The global production from the electronics and information technology industries is expected to grow by 3% in 2016, comprising largely of devices which can connect to the Internet such as smartphones (Japan Electronic and Information Technology Industries Association, 2016). This increase is mainly due to the development of high-speed radio communication network and growth in the market trends for devices like smartphones and tablets in emerging countries, in addition to the growth of new manufacturers meeting the demands of consumers looking for lower prices for electronic devices (Japan Electronics and Information Technology Industries Association, 2014). Globally, mobile devices have become the main tool for communication and internet access. The number of mobile phone subscribers is expected to increase from 1.8 billion in 2004 to 4.43 billion in 2017, and it is predicted that there will be approximately 6.9 billion subscribers by 2020 (Agency Federal Emergency Management, 2015; Statista, 2015). Similar to the growing global trend, mobile phones usage in Mauritius has grown from 130.9 per 100 inhabitants in 2014 to 139.5 per 100 inhabitants in 2015 (Statistics Mauritius, 2016).

In the residential sector, the average electricity consumption per electrified household in the world has increased from 3360 KWh in 2010 to 3374 KWh in 2014, and the average electricity consumption of households per capita was 733 KWh in 2014 (World Energy Council, 2015). Regarding the end-uses of residential electricity consumption, apart from the “traditional” end-uses of electricity such as lighting, space heating or cooling, there has been increase in “other” end-uses such as appliances, electronics and various miscellaneous equipment like mobile devices (Fanara, et al., 2015). The residential electricity consumption by end-use for the United States for the year 2014 is shown in Table 2.1. According to the table, the other uses which constitutes the biggest component (28%) includes small electric devices, heating elements, exterior lights, outdoor grills, pool and spa heaters, backup electricity generators, and motors. The US Energy Information Administration (EIA) has identified miscellaneous electricity consumption as all the energy which are not directly consumed from main sources like lighting, major appliances (white goods), water heating, air conditioning and space heating. Miscellaneous products vary substantially and examples of them include mobile phones, toasters, coffee makers, baby monitors or home security systems (Fanara, et al., 2015).

End use	Billion kilowatthours	Share of total
Space cooling	190	13%
Lighting	149	11%
Water heating	132	9%
Space heating	125	9%
Refrigeration	106	8%
Televisions and related equipment	88	6%
Clothes dryers	60	4%
Furnace fans and boiler circulation pumps	42	3%
Computers and related equipment	34	2%
Cooking	31	2%
Dishwashers	28	2%
Freezers	22	2%
Clothes washers	8	1%
Other uses	393	28%

Table 2.1: Estimated U.S. residential sector electricity consumption by end use, 2014
Source (US Energy Information Administration, 2016)

For the European countries, during the 10-year period from 2004 to 2014, the consumption of electricity by households fell by 1.3 %. There was much faster reduction in a number of EU Member States, in particular Belgium (with a reduction of 28.6 %), while reductions of more than 10 % were also recorded for the United Kingdom and Sweden. At the other end of the range, household electricity consumption rose in the other 18 Member States, generally by less than 10.0 %. Among the seven Member States with higher increases in electricity consumption, the largest expansions were recorded in Romania (48.1 %), Lithuania (27.1 %), Spain (21.8 %) and Bulgaria (20.8 %). These figures on overall household electricity consumption are likely to be influenced, in part, by the average number of persons living in each household and by the total number of households. Other influences include the extent of ownership of electrical household appliances and consumer goods as well as the use of energy saving devices (Eurostat, 2016).

The development, acceptance and increasing usage of technology to create, process and exchange information over the past decade has had a dramatic impact upon the consumption of electricity by office equipment in commercial buildings as well (U.S. Department of Energy, 2008). Office equipment is the fastest growing energy user in the business world, consuming 15% of the total electricity used in offices. This is expected to rise to 30% by 2020 (CarbonTrust, 2005). The key equipment categories found in offices are computer monitors and displays, personal computers, server computers, copy machines, computer network equipment, telephone network equipment, printers and uninterruptible power supplies. Commercial buildings account for approximately 40% of the total energy consumption in the world (United Nations Environment Programme, 2016). Commercial office and telecommunication equipment consumed a total of 97 TWh of electricity in the year 2000, which is equivalent to approximately 3% of the total electricity consumption in the United States (Roth, et al., 2004).

In Mauritius as well, there has been a rapid growth in the electricity sales. In the residential sector of Mauritius, the electricity consumption has been increasing by approximately 21.9 GWh per year from 2004 to 2014 (Ramgolam, et al., 2014). Electricity consumers in Mauritius can be categorized into three main groups, namely Residential, Commercial and Industrial. The structural changes in the domestic economy after the 1990s resulted in the augmented demand of electricity, as shown in figure 2.2. The graph shows the growth in electricity sales for each customer category (Residential, Commercial and Industrial). The upward trend in electricity sales was mainly due boost in the commercial and manufacturing sectors of Mauritius. In general, there is a direct correlation between income levels and electricity consumption. The improvement of national wealth in Mauritius led to a higher demand of electricity due to the growing purchase of household appliances, which resulted in the amount of electricity sales increasing by 3.9% from 2012 to 2013 (Central Electricity Board, 2013). Locally, electricity sales increased by 2.2% from 2452 GWh in 2014 to 2505 GWh in 2015. The per capita consumption of electricity increased by 2.0% from 1945 KWh in 2014 to 1984 KWh in 2015 (Statistics Mauritius, 2016).

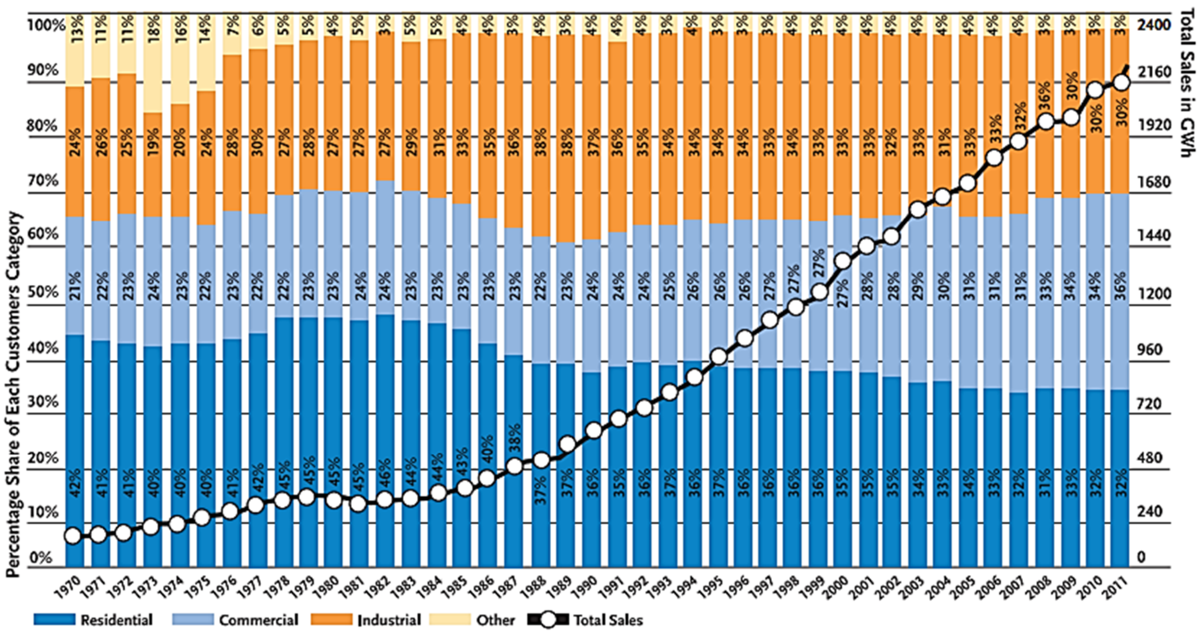


Figure 2.1: Evolution of Electricity Sales by Customer Categories 1970 to 2011
(Source: Central Electricity Board, 2013)

From 2007 to 2012, the proportions of households with appliances such as refrigerator, washing machine, microwave oven, vacuum cleaner, air conditioner and gas shower have increased. Mobile phones have become more popular during recent years. In 2012, 91.1% of households had at least one household member who possessed a mobile phone compared to 74.2% in 2006/07. On the other hand, the proportion of households with a fixed telephone decreased from 75.7% to 67.2% during the same period. In 2012, almost 43% of households indicated having a personal computer compared to just over 26% five years earlier. More households are equipped with a gas shower, 44.2% in 2012 against 34.9% in 2006/07. The share of households with electric shower declined from 19.6% to 14.2% during the same period (Statistic Mauritius, 2015).

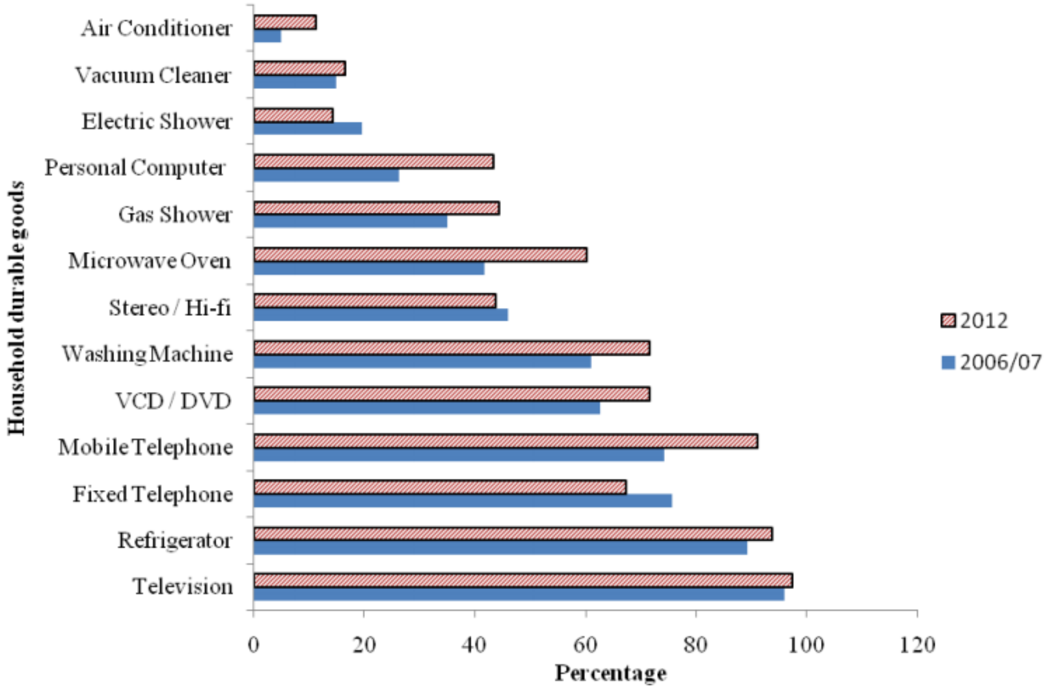


Figure 2.2: Distribution (%) of households with selected durable goods, 2006/07 and 2012 (Source: Statistics Mauritius, 2015)

With both economic and technological growth, electronic consumerism has increased significantly. In both global residential and commercial sectors, the number of electronic devices and appliances keep on increasing and, the electrical energy demand is even expected to rise by more than 25% from 2010 to 2040 in both sectors (Exxon Mobil Corporation, 2015). This growth in energy demand will inevitably have an impact on the natural environment and the rising carbon dioxide emissions.

2.2 The Growing Concern to the Environment

With the growing amount of electronic consumerism, there is a growing concern of its impact on the natural environment. The global environment has witnessed significant changes as a result of the exponential growth energy consumption (Michaelides, 2012). In both developed and developing countries, the household energy consumption contributes significantly to the total amount of energy consumed in the world (European Environment Agency, 2015). Residential and commercial buildings consume approximately 60% of the world's electricity (United Nations Environment Programme, 2016). The high usage of various domestic electrical and electronic appliances, lighting and space heating and cooling devices is responsible for the growing carbon dioxide (CO_2) emission (Department of Environment Food and Rural Affairs, 2002). It is estimated that 600 mega tonnes of CO_2 are emitted per year as a result of growing use of electricity and electronic devices, and this figure could surpass 1000 mega tonnes by 2030 (Horowitz, 2011).

According to a past research study, the total annual volume of electrical and electronic equipment waste reached approximately 41.8 million metric tons (Mt) globally in 2014 and it is estimated that this figure will increase to 50 million metric tons by 2018, while consisting of the main electronic devices given in Table 2.2 (Baldé, et al., 2015).

Electronic Device	Expected Weight (Mt)
Lamps	1.0
Screens	6.3
Small devices (mobile phones, personal computers, calculators, printers)	3.0
Appliances (microwave ovens, electric shavers, toasters, vacuum cleaners, video cameras)	12.8
Larger equipment (washing machines, dishwashers, electric stoves, clothes dryers)	11.8
Cooling and freezing equipment	7

Table 2.2: Estimated Weight of Electrical and Electronic Equipment Waste

The inadequate disposal and recycling techniques of electrical and electronic devices in order to recover metals such as gold and copper are causing significant and harmful damage to the environment (Sepúlveda, et al., 2010). With the growing amount new electronic goods usage, the amount of electronic and electrical wastes is growing at an alarming rate, especially in the OECD countries (Widmer, et al., 2005).

2.3 Mitigation of this Growing Concern

With the increasing environmental pressures associated with the electrical and electronic sector, there are more considerations being applied in the product design and development of consumer electronics in order to cater for the emerging green market (Gurauskienė & Varžinskas, 2006). From the life-cycle perspective, the most significant environmental concerns of the electrical and electronic equipment is the amount of energy consumed during their use (Lewis & Gertsakis, 2001). For example, the amount of energy has significant contributions to greenhouse gases and climate change. As such, there is a need to mitigate the growing consumption of electronic devices and reduce the amount of electrical energy associated with them.

There are legal requirements and standards which are also among the main drivers for environment-friendly design of electrical and electronics products. In Europe, there are various laws, along with the national electronics "producer responsibility" laws which emphasize and encourage companies to consider the environmental impacts of their electronic products by focusing on eco-friendly design and facilitating recycling. For example, the Directive (2002/96/EC) on Waste Electrical and Electronic Equipment (WEEE) encourages the production of electronic products which are easy to recycle, dismantle and ensure that the products are capable of being re-used (Institute for European Environmental Policy, 2009). The Directive (2002/95/EC) on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) states that both the suppliers and the producers need to be aware of all the materials being used in the production of electronics, in order to limit the use of harmful substances. The Directive (2005/32/EB) on Establishing a Framework for the Setting of Eco-design Requirements for Energy Using Products (EuP) encourages production companies to cater for the ecological aspects and designs before placing products on the market (Gurauskienė & Varžinskas, 2006). The main strategy to reduce electronic waste is to increase the durability of the appliances, as well as facilitating the disassembly and recycling process during the product development phase (Lewis & Gertsakis, 2001).

At the governmental level, different measures have been taken across various countries to reduce the electrical energy consumption from households and offices. For example, the Government of the Netherlands (2015) has concluded various agreements with businesses to promote energy conservation. Some of these are to provide low-interest loans for home-owners to fund energy saving measures such as floor insulation. Another measure is to improve to approximately 300, 000 homes annually to make them more energy efficient (Government of the Netherlands, 2015). The United Kingdom is adopting policies and programmes to reduce the energy demand across various sectors. One such programme for the household and commercial sectors is the Smart Meter Programme, which aims to provide consumers with electricity smart meters so as to measure and reduce their electrical energy consumption (Gov.UK, 2015). In Mauritius, the local government has set up the Power Sector Expansion Plan which seeks to use the least costly and clean technologies for supplying electricity. Apart from this, several other measures have been taken to mitigate the growing electrical energy consumption. For example, the Government is encouraging households and businesses to install Photovoltaic panels to generate their own electricity and sell the surplus to the Central Electricity Board. Another measure is the setting up of the solar water heater scheme, which aims at helping residents to reduce their electricity consumption (Maurice Ile Durable, 2015).

In addition to regulatory and governmental bodies, it is also important for individuals to reduce their electrical and electronic equipment usage since individuals are the main end-users of these devices. Some practical steps to reduce the electronic devices usage which can be taken by individuals are switching off the appliances when not in use, setting computers to sleep mode during periods of inactivity or using electricity monitor meters to measure the energy consumption of the appliances (Natural Resources Defense Council, 2015).

For this research study, the main focus is on the individuals and their ability to reduce their personal electronics consumption. This is because individuals have more control over their personal electronics appliances and by limiting their electronics usage, they can reduce their overall electrical energy consumption, hence resulting in a global electrical energy reduction.

2.3.1 Barriers to the Reduction of the Growing Consumption of Electrical and Electronic Devices

Different barriers have been identified which prevent individuals from reducing their electronics consumption. The main barrier is a lack of information dissemination and awareness on how to effectively reduce electronics consumption and the resulting energy use (UK Department of Energy and Climate Change, 2012). Even though people can generally identify the anthropogenic sources of climate change or rising energy consumption, there are some difficulties in understanding clearly the roles played by individuals in contributing to the growing electronics consumption and climate change (Poortinga, et al., 2006). There is a lack of information in the causes, consequences and possible solutions to energy consumption. One study has demonstrated that apart from the lack of knowledge, there is also a perceived lack of locally-relevant information in a format which can be easily understood by non-experts (Lorenzoni, et al., 2007). Another study conducted in U.S. households has shown the adults have a limited understanding of the effects of electronic products usage and the household devices activities and this is considered as a major barrier to energy efficiency in households (Vandenbergh, et al., 2011). Furthermore, there have been few studies that are explicitly focused on aiding household members in reducing their electrical energy consumption with the use of technology (Chetty, et al., 2008). According to psychologists, households can save up to 10% in energy with real time information at relevant times, proper feedback and goal setting abilities (Mccalley & Midden, 2002; Woods & Newborough, 2003). So far, the current ways of tracking household energy consumption are quite inadequate. For example, the use of utility bills does not provide people in the households with real-time feedback since most often, the bills arrive at the end of the month and thus, preventing users from immediately changing their consumption behaviours (Darby, 2000). On a commercial level, the products available such as Watts Up, rarely provide users with information on the total household electrical energy consumption (Chetty, et al., 2008).

In this research project, the main barrier being considered is the lack of awareness and knowledge regarding the energy consumption and most precisely, electronics consumption. This research seeks to bridge this gap between individuals and the accessibility of relevant information in order to reduce personal energy consumption from electronic devices.

2.3.2 Overcoming the Barriers

As discussed in the previous section, knowledge and proper feedback are the key barriers to reducing the consumption of electronic devices. As such, one of the ways to overcome this barrier is to raise more awareness and provide users with relevant information on how to reduce their energy consumption. One study showed that a very small percentage (5%) among the surveyed participants get environmental knowledge from Governmental agencies, and most of the participants mentioned social networking websites and radio channels as some of the primary sources of information (Dookhitram, et al., 2012). This implies that the current means of educating people through websites, flyers or media are not effective enough as knowledge and awareness is still being regarded as a barrier. As such, other self-learning tools need to be explored. One particular self-learning tool is Augmented Reality (AR). Numerous advantages are associated with AR. Augmented reality is considered to be one of the most popular and effective approaches to improve learning (Kose, et al., 2013). Regarding the interaction with the real-world, new developments in mobile technologies have a vital impact on existence of AR. Regarding mobile learning systems, it is observed that the satisfaction expressed by the users of these additional learning tools (of mobile learning). The users felt supported and motivated by the use of mobile applications with accessible language. In fact, the systems commonly used in m-learning, like mobile communication systems, as already mentioned, can, when integrated with AR contents, encourage observations and field explorations, because it is possible to explain the Reality observed with the (Augmented) addiction of virtual contents (among others: tutorial videos, schemes, three-dimensional images). This interaction contributes to higher autonomy in the learning process (Coimbra, et al., 2015).

2.4 Augmented Reality as an Effective Self Learning Tool

AR provides a bridge between the real and the virtual worlds, by incorporating virtual computer graphics into real three dimensional scenes (Pan, et al., 2006). There are three characteristics which are fundamental to an augmented reality interface. Firstly, there should be a combination of real and virtual, secondly the interface should be interactive in real time, and thirdly the system should be three dimensional (Azuma, 1995). Augmented reality technologies give room for the coexistence of virtual elements in the real world and allow for interaction with real objects as well (Antonacci, et al., 2008).

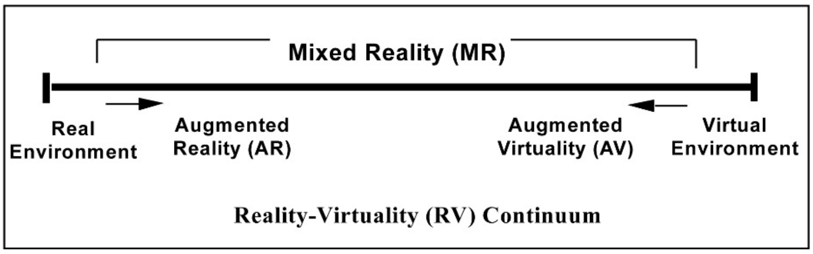


Figure 2.3: Milgram's Reality-Virtuality Continuum
(Source: Milgram & Kishino, 1994)

Since AR often relies on mobile devices, it also provides a tremendous advantage for just-in-time learning and exploration, without any special googles (Johnson, et al., 2011). Augmented Reality has the ability to aid individuals to view the world around them in new ways, and to engage in real issues in an already familiar setting (Klopfer & Sheldon, 2010). AR also has the potential to make self-learning more engaging and robust for any individuals (Zaman, et al., 2009). A previous study has demonstrated that AR systems and environments can help learners to develop skills and gain knowledge more effectively as compared to other technology-enhanced learning settings (Sayed, et al., 2011). Moreover, AR environments can also increase the interest and motivation of learners which can help them develop more investigation skills and gain more accurate knowledge on the topic (Rosenbaum, et al., 2007).

This technology has been explored and successfully implemented in various domain applications, such as museums and tertiary institutions. For example, London's Natural History Museum has implemented an AR tool to allow visitors to use handheld screens and explore the evolution of dinosaurs through interactive videos which show dinosaurs moving around the actual space of the museum (Johnson, et al., 2011). The Museum of London has developed a free mobile phone application called StreetMuseum letting users view information and 3D historical images overlaid on modern buildings and sites around the city of London. The application has been downloaded more than 10, 000 times and has a 3.8 rating on Google Play Store (Google , 2015). Apart from museums, AR is becoming popular among university media programs especially. The Georgia Institute of Technology has developed an augmented reality programming environment for children known as

"Augmented Reality Scratch" (Johnson, et al., 2011). In engineering education, an application was developed to aid students improve their spatial skills by performing graphic engineering exercises through AR. The result was a demonstrated improvement in the spatial capacity of students to understand geometric graphics (Martín-Gutiérrez, et al., 2010).

AR has been successfully implemented in various fields and has shown the potential to create effective self-learning environments for individuals (Martin-Gutierrez, et al., 2012). This emerging technology can thus be applied to overcome the earlier identified barriers to raise awareness and help individuals measure and reduce their personal electrical energy consumption. Therefore, it is vital to analyse existing AR tools which focus on promoting awareness on green consumption of electronic devices so as to be able to assess their effectiveness and how successful the tools are at engaging users.

2.5 Existing AR Tools to Promote Awareness on Consumption of Electrical and Electronic Devices

In the recent years, several tools and applications have been developed to promote green consumption on electronic devices. Those tools have made use of the emerging AR technology as a more effective means of engaging users towards environmental sustainability. A comprehensive Google search was performed to find out about relevant tools and applications, and each application was critically analysed and reviewed. The applications which were selected made use of AR as a main feature to raise awareness on electrical energy consumption. The following is a list of currently available tools for promoting awareness on green consumption of electronic devices:

- ***Dia Saves Energy*** – Dia Saves Energy is an AR mobile application freely available on both Android and iOS platforms. The application was developed as part of the energy conservation campaign in Saudi Arabia and makes use of marker-based AR feature to educate the local population on how to conserve energy in their homes. The application focused on three main components which were part of the campaign messages. These are using energy saving light bulbs, choosing energy saving white goods and using the air conditioning systems in a responsible manner. The main limitation with this application is that it raises awareness on three types of electrical products only, and not all the range of electrical and electronic appliances used at homes and offices. Since the application is marker-based, it also means that users cannot use the application without downloading the required markers. This mobile application cannot be used efficiently outside of Saudi Arabia and the application is available in the Arabic language only (Spectre, 2015; Google, 2015).
- ***iCEnergy***: ***Augmented Reality Display for Intuitive Energy Monitoring –*** iCEnergy is a prototype vision-based mobile information application which makes use of AR to allow users

to measure their power consumption of different devices. The system makes use of virtual clouds of different colours and sizes to indicate the energy efficiency status of different energy-consuming devices. The application also makes use of coloured landmarks to easily locate the different devices and then registers those coordinates on servers so as to display appropriate energy consumption information. iCEnergy mobile application has not been developed yet for commercial use, and therefore there are no user reviews of the application (Pan, et al., 2012).

- ***Energiency:*** Energiency is a new industrial application which allow users to embody in real time an operator in charge of manufacturing dairy products by using as little energy as possible. The application display energy savings and ways of reducing the electrical energy consumption from manufacturing processes. This application can be used in industries only and not at home or offices (Bretagne Commerce International , 2015).

From the application search conducted, it was found that there exists no specific application or software which uses augmented reality as a means of raising awareness on green consumption at homes or offices. The applications reviewed are either in their prototype phase and need further enhancement or cannot be applied for all the electronic appliances used at homes. From this review, it can be deduced that presently, mobile augmented reality has still not been fully explored as a self-learning tool for raising awareness on green consumption at homes or offices.

2.6 Hypothesis

As discussed in section 2.4, AR technologies have revealed to be effective self-learning tools for users (Martin-Gutierrez, et al., 2012). Since the last few years, there have been major developments in the application of AR to create immersive and more engaging learning environments for users (Martín-Gutiérrez, et al., 2010; Wu, et al., 2013). But presently, since there exists no augmented reality which aid users to track and reduce their energy consumption of electronic devices, the effectiveness of AR as a self-learning tool has yet to be assessed. Hence, the main research question of this research project is:

RQ: Can Augmented Reality be effectively used as a mechanism to improve self-awareness on green utilisation of electronic devices?

In order to further investigate and answer this hypothesis, the research study will be divided into four main phases as shown in Figure 2.4

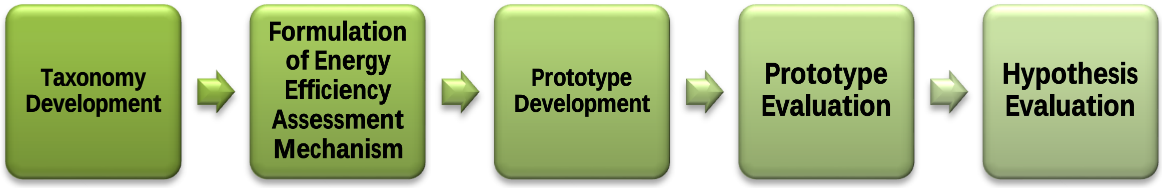


Figure 2.4: Main Phases of the Project

The main phases of the project are described below:

- Taxonomy Selection/Development:
  A taxonomy study will first be conducted on green consumption of electrical and electronic devices in order to identify the most commonly used and available electronic devices in the households and offices. Due to the increasing number and types of electronic appliances and devices, it is important to categorise the various existing electrical and electronic devices and appliances in both homes and offices based on some specific conditions, like the most commonly used or the same type of devices. This categorisation will help in identifying most of the appliances being used by consumers, and thus facilitating the calculation of individual carbon emission by each device. Based on the taxonomy study, it will be assessed whether one particular taxonomy will be adopted for the study or a new one will be developed.
- Formulation of Energy Efficiency Assessment Mechanism
  After conducting the taxonomy study, the next phase of the project is to develop a mechanism for assessing how energy efficient the users of electrical or electronic devices will be. The mechanism will help provide a quantitative analysis on how users adopt green practices and behaviours.
- Prototype Development:
  After developing the energy efficiency assessment mechanism, a prototype augmented reality mobile application will be developed. The main objective of this prototype is to enable the use AR to engage users in reducing electrical energy consumption. The application will target mainly electrical and electronic devices and appliances in both homes and offices and inform users of the amount of energy being consumed by each device, the amount of carbon dioxide emitted over a particular period of time and help users to reduce their energy consumption by informing them of the best practices towards a greener lifestyle. The prototype will help implement a more visual and interactive approach and to help answer the main research question.

- Prototype Evaluation:

  When the prototype mobile AR application has been developed, the main features and functionalities will be tested and evaluated using selected evaluation techniques. Based on the results of the evaluation, the design and functionalities of the application will be further improved.
- Hypothesis Evaluation:

  As per the main aim of this study, a user testing will be conducted in order to understand whether the AR feature in the application is effective to raise awareness on the green utilization of electronic devices. Using appropriate evaluation methods, users will be asked to use the application for a certain period of time so as to track and reduce their electronics consumption. The results of evaluation will be used to answer the main hypothesis of this research study.

2.7 Chapter Summary

From the literature review conducted in this chapter, it was found that the electronics consumption are on the rise both internationally and in Mauritius. The number of electrical and electronic appliances used in homes and offices have considerably increased due to various reasons such as economic and technological development and growth of population. This has in turn caused different environmental harms like electronic wastes and rising carbon emissions. In order to mitigate these environmental concerns, it was discussed that new and more effective solutions need to be proposed to aid individuals reduce their electronics consumption. A review of existing AR applications was conducted. The chapter ends by highlighting the main hypothesis of this study and how the hypothesis will be investigated and evaluated. In the next chapter, a detailed analysis will be presented on the taxonomy study conducted.

Chapter 3- Green Consumption of Electronic Devices – A Taxonomy Study

Chapter 2 provided a detailed insight on the rising consumption of electrical and electronic devices in both households and offices. It has been estimated that 600 mega tonnes of CO_2 are emitted per year as a result of growing use of electricity and electronic devices, and this figure could surpass 1000 mega tonnes by 2030 (Horowitz, 2011). There are two ways of reducing CO_2 emissions. The first way is to reduce the consumption of energy, by maintaining or even increasing utility and performance of appliances. The second way is to replace fossil fuels by new types of energy sources which either have lower CO_2 intensities (CO_2 per energy output) or result in no emission of carbon at all, for example renewable energy sources (Alfredsson, 2002). This research focuses on the first method that is, reducing the consumption of energy, most specifically electrical energy because most of the electrical energy generated in Mauritius are still through non-renewable sources. There is a need to understand how the individual electronic devices contribute to the rising carbon emissions, and by which amount so as to limit and reduce their consumption. Chapter 3 gives a detailed analysis on the green consumption of electronic devices, along with a categorisation of the various electrical and electronic devices at homes and offices.

3.1 Green Consumption of Electronics

Green consumption refers to the use of products which do not cause damage to any natural ecosystem and helps to maintain environmental sustainability. One study has associated green consumption with scientific indications and it was defined as the energy or CO_2 emissions per monetary unit associated with devices and products (Alfredsson, 2004). According to the same study, green consumption ranges from institutional arrangements to individual behavioural changes and four categories have been identified in the definition of green consumption. Travel, housing and food are considered the first three categories. The fourth scenario combines all three scenarios into an overall "green" consumption scenario, which includes realistic changes in behaviour and technological changes for an environmentally sustainable lifestyle (Alfredsson, 2004). Due to the lack of clarity in the idea of green consumption, some studies chose to orient the concept towards sustainable development, similar to the definition provided for sustainable consumption by UNEP (2001). The definition is as follows:

"*a number of key issues, such as meeting needs, enhancing quality of life, improving efficiency, minimising waste, taking a life cycle perspective and taking into account the equity dimension, for both current and future generations, while continually reducing environmental damage and the risk to human health*" (UNEP, 2001). The UNEP definition focuses on the impact the products have on the natural environment during their life spans and after being discarded as well. The definition includes the whole life cycle of the products and how these products affect environmental sustainability.

Other studies defined green consumerism as "*the purchasing and non-purchasing decisions made by consumers, based at least partly and environmental or social criteria*" (Peattie & Moira, 1992). This definition focuses more on the behaviours of consumers and how their environmental concerns affect their consumption decisions.

Another definition is green consumption refers to the "*use of individual consumer power to promote less environmentally damaging consumption, while still satisfying consumer wants and needs*" (Charter, et al., 2002). This definition is also based on the behaviours of consumers and their ability to choose eco-friendly products which also meet their needs and wants.

All the definitions discussed above are related to this research study, and since the aim of this study is to help individuals measure and reduce their personal electricity consumption while using different electrical and electronic appliances, the last definitions is considered to be a suitable definition to be used for this research.

3.1.1 The LCA Approach and Green Consumption of Electronics

Based on the selected definition for green consumption, the Life Cycle Assessment (LCA) methodology is most appropriate to use so as to better understand the green utilization of electronic and electrical appliances. According to UNEP (2015), LCA is a tool which allows for the systematic evaluation of the environmental impacts of a product or service throughout all the stages of its life cycle that is, including the emissions and resources used during production, distribution, use and disposal (UNEP, 2015; Hertwich, 2005). LCA studies have demonstrated that similar products can have different environmental impact including energy requirements and related carbon emission (Alfredsson, 2002).

In this research, the focus is not on conducting a full LCA study, but rather on analysing the electrical energy consumption of electronic products present in households and offices. The LCA methodology for a greener consumption of electronics has been chosen due to the various opportunities the LCA tool present to reduce the environmental impacts of products throughout their life cycles (Scipioni, et al., 2010). Therefore, through behavioural changes that lead to individuals choosing products with lower environmental impact, for example, lower embodied energy requirements and CO_2 emissions compared to other products, energy requirements and CO_2 emissions from this type of consumption can be reduced (Alfredsson, 2004). The choice for energy as a proxy of environmental load has two reasons. Firstly, energy use has impact on three environmental issues: resource depletion, local/regional environmental impact and global impact. Secondly, the energy statistics are the best available environmental data and provide the possibility to calculate energy requirements in relation to consumption. Therefore, household and office consumption is studied by means of energy analysis in this research study.

The various product stages that a typical LCA spans include, but are not limited to: raw material acquisition, material processing, manufacture and assembly, use and service, retirement and recovery and disposal. Each of these stages can include material and energy inputs as well as waste outputs (Jeong, et al., 2010).

3.2 Need for Taxonomy

The first objective of this research project is to establish a taxonomy of the electronic appliances used in both households and offices so as to reduce their carbon emissions and environmental impacts at the individual household and office levels. Since the 1990s, the amount and types of miscellaneous electrical and electronic products found in buildings have increased considerably (Nordman & Sanchez, 2006). This resulted in a significant increase in electrical energy use in both houses and offices. Despite the harmful consequences of the increasing amount of electronic equipment use, there has been little research performed on how electricity is being consumed through specific devices (Almeida, et al., 2010). According to Gallachóir (2007), it is a necessity to collect data on the energy supply and end-use so as to propose better policies towards increased sustainability. As such, in order to promote green consumerism and energy-conscious behaviours towards electronic equipment usage, there is the need to create more awareness and understanding among the population on their interaction with various equipment used at homes and offices (Woods & Newborough, 2003). In order to provide detailed and more efficient information on the individual electricity usage in households and offices, there needs to a proposed taxonomy, or categorization, of the different electrical and electronic appliances available in houses and offices. The taxonomy will help to categorise and provide an organised view of different main types of electrical and electronic appliances used in both homes and offices, and therefore will give a better overview of the normal electricity usage of a person in a typical day. From this taxonomy, each identified appliance can thus be further investigated to determine its electrical energy usage and energy efficiency practices for each category.

3.3 Existing Taxonomy of Electronic Devices

From literature, there exists some taxonomies which have been produced to provide an effective insight on the list of electrical and electronic devices present in homes and office buildings. One such taxonomy was proposed by H.Y.Lam (2007), who used a methodology based on load signatures to create a taxonomy of electrical appliances. A load signature is an electrical expression that an appliance uniquely possesses and could be in the form of power consumption or waveforms and harmonics (Lam, et al., 2007). Load signatures can be used for identifying and tracking appliance usages, which can lead to determining detailed energy usage of the appliances, or detecting energy efficiency, among other advantages (Cheng, et al., 2006). The methodology used for producing that taxonomy was first measuring the voltages and current waveforms from the household appliances, constructing the load signatures in the form of the voltage against current trajectory, extracting the shape features from the trajectories, applying a hierarchical clustering method to group all the appliances, and finally building the taxonomy based on the identified groupings (Lam, et al., 2007). The resulting taxonomy is shown in Figure 3.1:

THE TAXONOMY OF THE APPLIANCES

Main Group	Subgroup
1 – Kettle, incandescent lamp, fan, vacuum cleaner, heater, air conditioner	1.1 – Kettle, incandescent lamp, air conditioner 1.2 – Fan 1.3 – Vacuum cleaner 1.4 – LCD television
2 – Fluorescent lamp with conventional ballast, CD player, battery charger, refrigerator, dehumidifier	2.1 – Fluorescent lamp with conventional ballast, refrigerator, dehumidifier 2.2 – CD player, battery charger
3 – CD player and LCD television in stand by mode	
4 – Hair dryer operates at low power mode (asymmetric trajectory)	
5 – microwave oven	
6 – Energy-saving light bulb, fluorescent lamp with electronic ballast, notebook computer, induction cooker	6.1 – Energy-saving light bulb, fluorescent lamp with electronic ballast 6.2 – Notebook computer 6.3 – Induction cooker
7 – Desktop PC, television, video cassette recorder, scanner, laser printer, mobile phone battery charger	
8 – Stand by mode appliances, e.g. desktop PC, LCD monitor, induction cooker	
Others - e.g. projector and washer	

Figure 3.1: Taxonomy of Electrical Appliances Based on Load Signatures
(Source: Lam, et al., 2007)

Based on the results obtained when developing the trajectories of the electrical appliances, all the electrical equipment analysed in the household have been grouped together. The main limitation with this study is that only selected appliances (resistive appliances, motor-driven appliances, pump-operated appliances, electronic appliances and fluorescent lighting) have been chosen for the experiment, and thus not all electrical and electronic devices present in households and offices have been identified. Another drawback is the taxonomy does not provide any detailed classification of the electronic appliances based on their energy consumption or amount of carbon emitted.

Nordman and Sanchez (2006) proposed another more detailed taxonomy based on miscellaneous and low power products. The taxonomy primarily includes electricity usage from both residential and commercial buildings. The structure of the taxonomy covers miscellaneous and low-power mode product types. Miscellaneous are appliances which are not included in the traditional end uses of electricity and the new end use of electronics products. The proposed taxonomy is shown in Figure 3.2.

Electronics

Audio

Amplifier
Audio minisystem
Cassette deck
CD player
CD player, portable
Charger, digital music player
Equalizer (audio)
Home theatre system
Karaoke machine
Musical keyboard
Radio, table
Receiver (audio)
Speakers, powered
Speakers, wireless (base station)
Speakers, wireless (speakers)
Stereo, portable
Subwoofer
Tuner
Turntable (audio)

Computer

Computer, desktop
Computer, integrated-CRT
Computer, integrated-LCD
Computer, notebook
Dock, notebook

Display

Computer display, CRT
Computer display, LCD
Computer display, plasma screen
Game console, portable
Projector, slide
Projector, video
Television, large CRT
Television, LCD
Television, plasma
Television, rear projection
Television, standard CRT
Television/VCR

Imaging

Copier
Fax, inkjet
Fax, laser
Fax, thermal
Multi-function device, inkjet
Multi-function device, laser
Printer, inkjet
Printer, laser
Printer, photo
Scanner, flatbed

Networking

Hub, ethernet
Hub, USB
Modem, cable
Modem, DSL
Modem, POTS
Router, ethernet
Wireless access point

Peripherals

CD recorder
Dock, PDA
External drive
Speakers, computer

Security

Security system

Set-top

Set-top box, analog cable
Set-top box, digital cable
Set-top box, digital cable with PVR
Set-top box, game console
Set-top box, game console with internet connectivity
Set-top box, internet
Set-top box, PVR
Set-top box, satellite
Set-top box, satellite with PVR

Telephony

Answering machine
Caller ID unit
Charger, mobile phone
Phone
Phone, conference
Phone, corded
Phone, cordless
Phone, cordless with answering machine

Video

Charger, still camera
Charger, video camera
DVD player
DVD recorder
VCR
VCR/DVD
Videocassette rewinder

Miscellaneous

Business equipment

Adding machine
Pencil sharpener
Shredder
Stapler
Typewriter

Toaster
Toaster oven
Vacuum, central
Vacuum, rechargeable
Vacuum, standard
Waffle iron

Garage door opener
GFCI outlet
Infant monitor, receiver
Infant monitor, transmitter
Utility meter
Wire losses

Electric housewares

- Automatic griddles
- Blanket
- Blender
- Bread maker
- Broiler
- Clock
- Clock, radio
- Coffee grinder
- Coffee maker, residential
- Corn popper, air
- Corn popper, hot oil
- Deep fryer, residential
- Espresso maker, residential
- Food processor
- Food slicer
- Frying pan
- Hand mixer
- Heating pad
- Hot plate (kitchen)
- Iron
- Juicer
- Kettle
- Knife
- Mug warmer
- Oven, microwave
- Pasta maker
- Rice maker
- Sewing machine
- Slow cooker
- Stand mixer

Hobby/leisure

- Aquarium
- Kiln
- Pool
- Sauna, electric
- Spa/hot tub

HVAC

- Air cleaner, mounted
- Air cleaner, portable
- Air conditioning, evaporative cooler
- Ceiling fan
- Dehumidifier
- Exhaust fan
- Fan, portable
- Fan, rangehood
- Fan, whole house
- Fan, window
- Furnace fans
- Heating, fireplace electric
- Humidifier
- Space heater, portable (electric)
- Space heater, portable (non-electric)

Infrastructure

- Breaker, AFI
- Breaker, GFCI
- Detector, carbon monoxide
- Detector, smoke
- Doorbell

Lighting

- Dimming switch
- Emergency light, interior (commercial)
- Grow lamps
- Lamp, decorative
- Lights, holiday
- Low voltage landscape
- Motion sensor, exterior
- Motion sensor, interior
- Night light, interior
- Photosensors, exterior
- Timer, exterior
- Timer, interior

Major Appliance

- Garbage disposal
- Refrigerator, wine cooler
- Trash compactor
- Water dispenser, bottled

Other

- Fountain, indoor
- Waterbed

Outdoor Appliances

- Charger, hedge trimmer
- Charger, weed trimmer
- Coil, snow melting
- Grill, outdoor
- Lawn mower
- Timer, irrigation

Personal Care

- Air freshener
- Curling iron
- Hair dryer
- Heat lamp
- Home medical equipment
- Massager
- Shaver
- Toothbrush
- Water softener

Power

- External power supply
- Power strip
- Power supply
- Surge protector
- Timer
- Uninterruptible power supply

Transportation

- Auto engine heater
- Car, wheelchair or golf cart

Utility

- Bicycle light
- Charger, battery
- Floor polisher
- Pet fence
- Power tool
- Power tool, cordless
- Pump, sump
- Pump, well

Water heating

- Water heating, instantaneous single point of use
- Water heating, point of use tank

Traditional End Uses

HVAC

- Air conditioning, central
- Air conditioning, heat pump
- Air conditioning, room/wall
- Heating, boiler
- Heating, furnace baseboard, floor or wall unit
- Heating, furnace central
- Heating, heat pump

Lighting

- Lighting, residential

Major Appliance

- Clothes dryer, electric
- Clothes dryer, gas
- Clothes washer, horizontal axis
- Clothes washer, standard
- Cooktop, electric
- Cooktop, gas
- Dishwasher
- Freezer
- Oven, electric
- Oven, gas
- Refrigerator

Water heating

- Water heating, electric
- Water heating, gas
- Water heating, heat pump
- Water heating, other

Figure 3.2: Taxonomy for miscellaneous and low-power appliances (Source: Nordman, 2006)

For the project, the taxonomy in Figure 3.1 is chosen since it covers most of the appliances used in homes and offices and is within the scope of the project. The second taxonomy (Figure 3.2) is also relevant but it too detailed, and it will not be possible to cover all the listed appliances in the prototype mobile application to be developed. As such, the first taxonomy is a better choice and the appliances mentioned can be used in the mobile application development.

3.4 Techniques and Best Practices towards Green Consumption of Electronic Devices

It is the responsibility of everyone to try to adopt a holistic approach towards a greener and environment friendly lifestyle. There are various ways which exist to reduce the negative environmental impacts of the electronic devices listed in the chosen taxonomy in Figure 3.1. Some of the techniques and best practices for the different devices are listed below:

- *Kettle:* Use ECO kettles since those kettles can boil the same amount of water with 20% less energy than conventional electric kettle (Energy Saving Trust, 2015). It is also recommended to fill the kettle with only the amount of water needed so as to save electrical energy used in boiling water (uSwitch, 2015).
- *Incandescent Lamps:* Replace traditional incandescent lamps with compact fluorescent light bulbs since the latter produce the same amount of luminance with far less energy. In traditional lightings, almost 90% of the energy is wasted as heat (Wang & Zhou, 2014).
- *Air Conditioner:* Air conditioners should be well maintained in order to be more energy efficient. The air filter should be regularly cleaned since a dirty air filter reduces the energy efficiency. Energy star central air conditioning systems are more efficient since 14% less energy are consumed as compared to standards air conditioners (Hearst Communications, Inc, 2015).
- *Fan*: Ceiling fans are considered to be more energy efficient than table or floor fans since air are more effectively circulated in the room. To increase the efficiency, ceiling fans with larger blades should be put 7 to 9 inches above the floor (U.S. Department of Energy, 2015).
- *Vacuum cleaner*: The energy labels should be checked for energy efficiency when buying vacuum cleaners. When using the vacuum cleaners, the filters should be changed regularly so that the air flow is not blocked. The appropriate nozzles should be used in order not to affect the performance of the vacuum cleaners (European Commission, 2013).
- *LCD Television:* Larger television sets consume more energy than smaller televisions, regardless of the energy rating or their types (LED, LCD or plasma). Televisions should also not

be left on standby modes since leaving them on standby modes can consume up to 20% of electricity as when switched on (Sustainable Energy Authority of Ireland , 2013).

- *Refrigerator:* Use energy efficient models, such as the A+ ones, since freezers are usually switched on every day for twenty-four hours. To reduce the energy consumption, the temperature of the refrigerators should be set at 38-42 degrees Fahrenheit and the doors should be tightly sealed (Natural Resources Defense Council, 2015).
- *CD player:* CD Players should not be left on standby mode when not in use (Sustainable Energy Authority of Ireland , 2013).
- *Battery Charger:* When batteries are charged, battery chargers need to be unplugged since chargers draw electrical power continuously even when the devices have been removed from the chargers (Duke Energy Progress, 2015).
- *Hair dryer:* Hair dryers should be switched off when not use, or set to switch off automatically (Energy Australia, 2015).
- *Microwave Oven:* Microwave ovens use 70-90% less energy than conventional ovens and should be unplugged when not in use (PowerHouse, 2015).
- *Induction Cooker:* Use ovens having an 'A' energy rating is the most efficient oven type and consume 40% less energy than B rated oven (Energy Saving Trust, 2015). Another energy efficient practice is to always use the right size of pan for the amount of food being cooked (uSwitch, 2015). When the oven is in use, the oven door should not be opened because this lets out the heat, resulting in an increase in cooking time (Natural Resources Defense Council, 2015).
- *Desktop Personal Computers:* The energy consumption associated with the use of desktop computers or laptops can be significantly reduced by taking small measures such as turning off the system when it is not in use or using blank screensavers rather than display images since the images are constantly interacting with the central processing unit of the computer. Another best practice is adopting the use of thin client computers that is remotely accessed desktops which use about one fifth of the power of desktop computers. Energy power management features can also reduce the energy consumption of computers. By using the sleep mode on most computers, the energy use can be reduced by approximately 60-70% since it is an easier option than not having to turn off the personal computers every time (Murugesan, 2008).
- *Video Cassette Recorder:* Video Cassette Recorders, like CD players, should not be left on standby mode when not in use (Sustainable Energy Authority of Ireland , 2013).

- *Scanner:* Scanners can be automatically configured to enter standby modes when inactive or low-power sleep mode (The State Electronics Challenge, 2015).
- *Laser printer:* Printers can also be configured to standby modes or sleep modes when not in use and Energy Star rated devices should be used for increased energy efficiency (Wake Forest University, 2009).
- *Projector:* Projectors should be set to switch off automatically after a certain period of time when not in use. Furthermore, projectors equipped with smart light sources can be used so that the brightness and brilliance are automatically adjusted depending on the amount of light in the room (Enervee, 2015).
- *Washing Machines:* To reduce energy consumption while using washing machines, the water level should always be set according to the load of the clothes and clothes should be washed with cold water as much as possible (Natural Resources Defense Council, 2015).

3.5 Chapter Summary

The green consumption of electronic devices was investigated in this chapter, as well as the relevant definitions of green consumption. The chapter also summarises the need for a taxonomy study for electronic devices. A few existing taxonomy studies were reviewed and since most of them were relevant to the study, there was no need to propose a new taxonomy for electronic devices at homes and offices. One of the reviewed taxonomy was selected to be used for the development of the AR application. After selecting the taxonomy, a list of the best practices towards green consumption of electronics was proposed for each of the appliances mentioned in the taxonomy.

Chapter 4– Application Design

From the literature review conducted in Chapter 2 and 3, it was shown that at present, there exists no effective AR tools to promote green consumption of electronics. The existing AR tools and applications identified cannot be used to determine the energy consumption of many electronic appliances at home, and hence making it impossible to assess their effectiveness in raising awareness on green consumption. Therefore, as per the second objective of this research study, a prototype AR application will be developed to assess the effectiveness of using AR to improve awareness on green consumption of electronic devices. This chapter outlines the design phase of the application, which includes identifying the functional and non-functional requirements, developing wireframes of the user interfaces and presenting appropriate design diagrams to show the different functionalities of the system.

4.1 System requirements

In this section, the functional and non-functional requirements of the mobile application are defined. Functional requirements are the capabilities and functions that the application should perform successfully. The Non-Functional Requirements are the qualities and criteria which are used to assess the operation of the application.

4.1.1 Functional Requirements

A functional requirement defines a function of the system. Functional requirements are supported by non-functional requirements, which impose constraints on the design on the application. The format chosen to represent the functional requirements of the prototype is as follows:

ID: *The identification number of the functional requirement*

Description: *The functional requirement.*

Explanation: *An explanation of the requirement, and its purpose whenever needed.*

The functional requirements of the application are outlined in Table 4.1.

ID	***Description***	***Explanation***
F1	Users must be able to scan their environments	The application should have a menu button to allow users to scan their current environments so as to identify any electronic appliances in use.
F2	The system should automatically detect electronic appliances present within the camera view of the mobile phones	In the scan menu, the application should automatically detect electronic appliances present in the camera view of the mobile phones of users and highlight the identified appliances by displaying a "Turn ON/OFF" virtual button above them.
F3	Users must be able to activate the appliances in use in the application	When scanning their environments, users should be able to choose the "Turn ON" virtual button on the screen so as to select any electronic appliances they are currently using.
F4	Users must be able to deactivate the appliances after switching them off in real time	After switching off their electronic appliances in real, users should be able to select the "Turn OFF" virtual button on the screen as well so as to ensure the system is detecting the correct amount of time they have been using the appliances.
F5	The system should display the amount of energy consumed by an appliance at any given time	When the user scans any appliances again, the application should calculate the total amount of energy consumed by that appliance for the time it was in use.
F6	The system should make use of colour coded icons to indicate the energy levels consumed by an appliance	When the system displays the amount of energy consumed, it should use a colour coded "energy" icon to indicate to the user whether the energy consumed by the appliance has exceeded the average energy consumption level of the device. Three colour codes can be used, "green", "orange" and "red".
F7	The system should provide tips to the user on how to reduce the energy consumption of an appliance	A minimum of three tips need to be provided for each appliance to help users take actions in reducing their energy consumption. A tip should also be displayed when the energy icon of an appliance turns orange and red. Tips should be displayed in an alternating way.

F8	The system should have a menu to show users their electrical energy consumption	Users should be able to select a menu to view their total daily energy consumption for all electronics used at homes and offices in KWh.
F9	The system should be able to calculate the total daily energy consumption for all electronic appliances used	The application should be able to add and display the total electrical energy consumed from all electronic appliances used in a day.
F10	The system should save the total energy consumption of all electronics devices	The application should save the total energy consumption for all appliances used to allow users to compare their everyday electrical energy consumption during a week.
F11	After the user has deactivated an appliance, the system should save the energy consumed for tracking	When the user selects the "Turn OFF" virtual button for an appliance, the application should save the amount of energy consumed to allow users to track their energy consumption for that particular appliance.
F12	The system should display the individual energy consumption of individual appliances	In order to track and reduce the energy consumption, users should be able to view the energy consumed for each appliance per day. This should be displayed in the form of a bar chart.
F13	The application must automatically save new tracked electronic appliances	The system should automatically save and add all tracked electronic appliances to the database
F14	The system should have a menu to guide users on using the application	Users should be able to access a help menu to know how to use the application

Table 4.1: Functional Requirements

4.1.2 Non-functional requirements

A non-functional requirement describes how the application will achieve the different functionalities in terms of, for example, system performance requirements, system external interface requirements, design constraints and software quality attributes.

The most important classes of the non-functional requirements are presented below based on their importance:

- Usability: is the ease with which a user can learn to operate, prepare inputs for, and interpret output of system.
- Modifiability/Extensibility: The ability of the system to be easily changed to meet new requirements.
- Portability: The ease with which a system or component can be transferred from one environment to another.
- Flexibility: The ability of the system to easily exchange information with the user.
- Reliability: is the ability of a system to perform its required functions under stated conditions for a specific period of time.
- Security: login, password requirements.
- Performance: concerns the speed of operation of a system.

The non-functional requirements of the application are given in the table below:

ID	***Description***	***Explanation***
NF1	The graphical user interface must be easy enough for anyone and all screens should have a similar style.	The buttons, menus and layouts should be the same in all the screens of the application. The users will execute specific actions in a certain way.
NF2	The system must be bug-free and inform the user of every wrong operation.	The system must be checked for any possible bugs in its operations before it is released to users. Also, it must provide log error messages (notification messages) to users to inform them of any wrong operation
NF3	The system will have fast response time.	The system should provide all its operations very fast. The user must not wait for any operation for a long time.
NF4	The system must be designed to be able to accept new operations and features.	The system must be designed in such a way that any developer can add new operations and features to the source code.
NF5	The system will be able to run on all Android devices.	The system will be developed to run on all Android devices, such as mobiles, tablets or any other device that uses the Android operating system.

Table 4.2: Non-functional Requirements

4.2 Design Diagrams

This section describes in detail the structure of the mobile application system and how the system will be implemented. It represents the application components and determines their appropriate placement and use within the overall structure.

4.2.1 User Interface Designs

In order for the application to satisfy the system requirements and maximize usability, it is very important to design the user interfaces of the application first. Mobile application design can be difficult and as such, specific mobile application design patterns such as RelativeLayout and LinearLayout are used to create the user interfaces for the AR application.

4.2.1.1 Layout Structure

For the layout structure of the application, three layouts are used to support all screen orientations of the devices. These are LinearLayout or RelativeLayout wrapped by ScrollView. Figure 4.1 and Figure 4.2 show the Main Menu screen in different screen orientations.

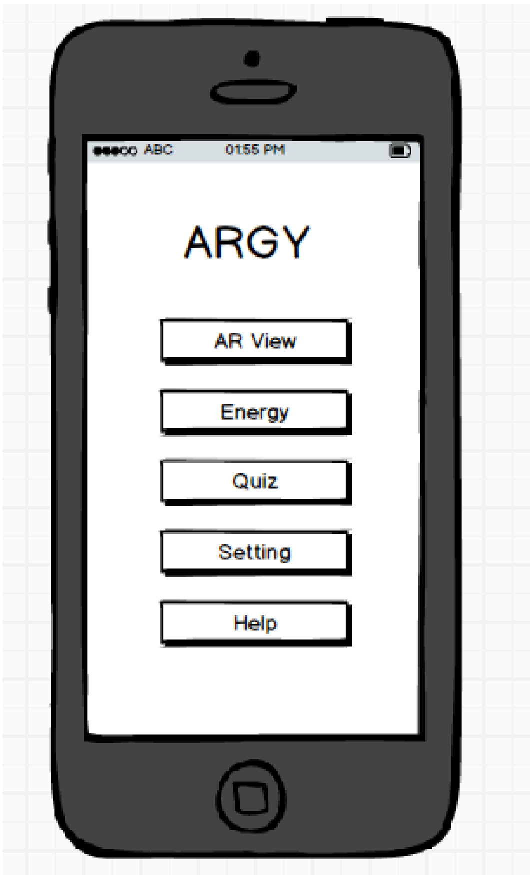


Figure 4.1: The Main Menu Screen in Portrait Orientation

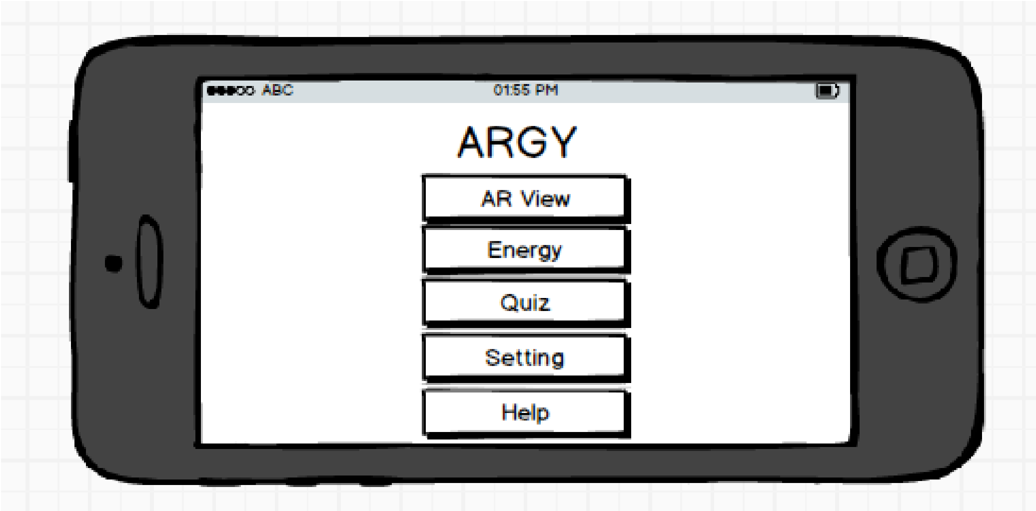


Figure 4.2: The Main Menu Screen in Portrait Orientation

4.2.1.2 Navigation and Controls

Each screen has navigation to other screens. The main menu uses List Menu design pattern for navigation to other screens as shown in Figure 4.3. The main menu redirects the user to the AR View, Energy, Quiz, Setting and Help screens. The AR View screen allows the user to scan electronic appliances in his/her surrounding. The Energy screen allows the user to view the daily energy consumption from the electronic appliances that have been used. The Setting screen gives the user the option to deactivate sounds features on the application. The Help screen shows the user how to use the application, for example, how to scan objects in their surroundings or track their energy consumption. The Quiz screen has a set of multiple choice questions for users to answer so as to test their knowledge on green consumption practices.

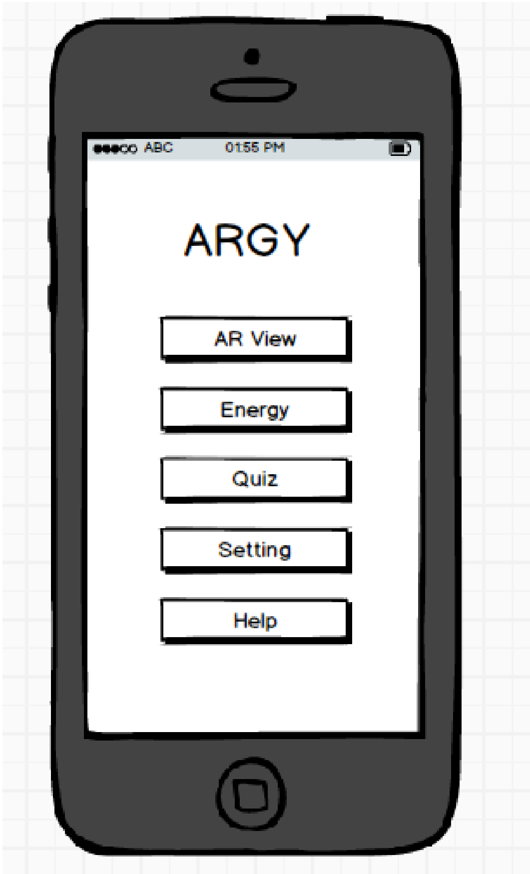


Figure 4.3: Home Screen of Mobile Application

In the application, all controls are displayed at the top of the screen or on the left of the detected appliances for the AR view menu. An example of the application controls for the AR View screen in shown in Figure 4.4. From the controls provided in the AR View screen, users have the option of going back to the home screen using the Home icon, choosing to start or stop scanning their appliances using the Switch icon, view additional tips on how to efficiently use an appliance so as to reduce its electrical energy use and finally, to assess their energy efficiency level using the Energy icon.

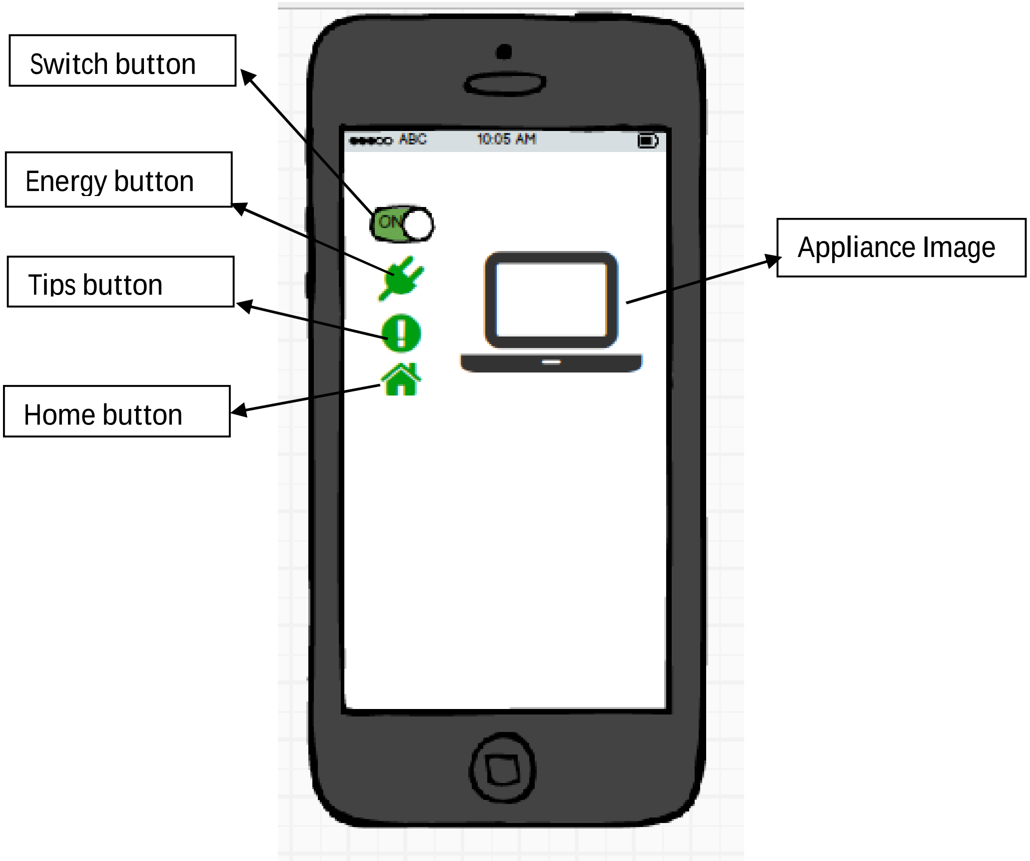


Figure 4.4: AR View Screen with Control Buttons

4.2.1.3 Help Feature

As mentioned in the functional requirement F14, the application will also have a help feature to guide users on how to best utilize the application. The user guide is provided in the Help menu and will contain textual information on how to use the different features of the application. The Help screen is shown in Figure 4.5, and the final text information will be added in the application development stage.

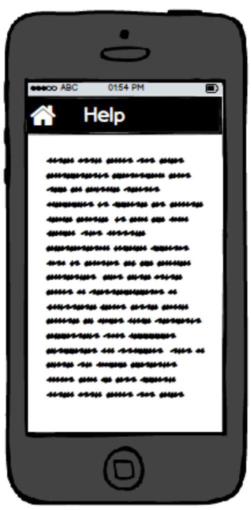


Figure 4.5: Help Menu

4.2.2 Use Cases

In software and systems engineering, a use case is a list of steps which defines interactions between actors and a system and the functional requirements, to achieve a goal. An actor is a person, organization or external system that plays a role in one or more interactions with the system. For this application, the actors which have been identified are the user and the web server. The use case diagram for the system is shown in Figure 4.6.

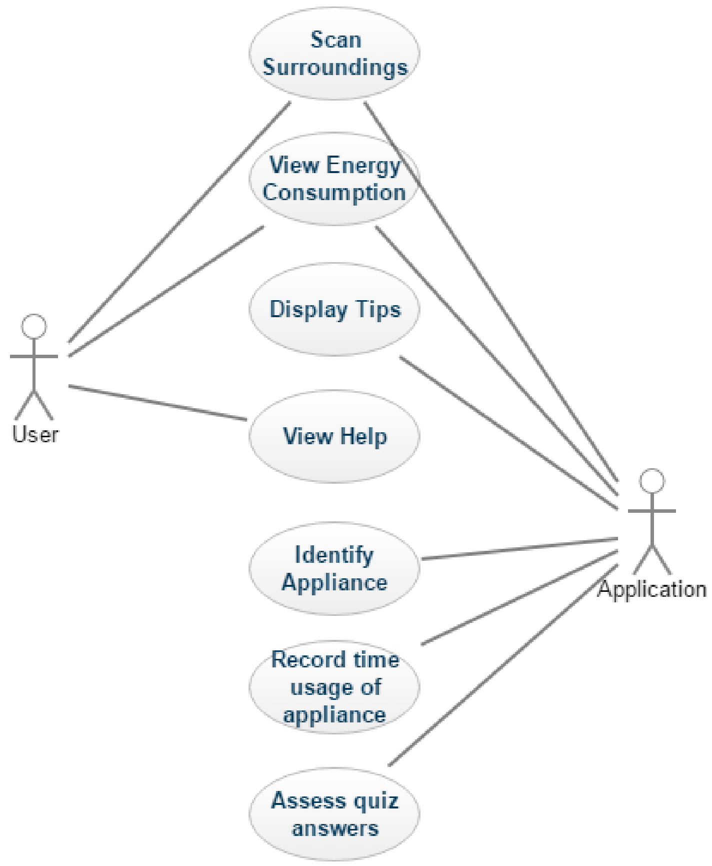


Figure 4.6: Use Case Diagram of Mobile Application System

The use case diagram in Figure 4.6 shows all the main processes occurring the mobile application between the two main actors, that is, users and the application. The following sections describe the use case scenarios for all the use cases mentioned in the diagram.

4.2.2.1 Use Case Scenarios

In this section, all the use case scenarios are described for both actors involved. Each use case scenario is given in a table format. The use case scenarios are outlined in the following way:

- Use Case Name: The name of the use case being described
- Context: The situation in which the use case is being applied

- Actor: The actor(s) involved in the use case scenario
- Precondition: The situations for which the use case is applicable
- Post Condition: What happens after the use case has been successfully applied
- Main Success Scenario: Step-by-step description of what happens when the use case is being successfully applied

Use Case Name	Scan Surrounding
Context	Electronic appliances need to be identified or disabled
Actor	User and Application
Precondition	Application is running, user has selected the Scan button
Post Condition	Electronic appliances used by user has been successfully identified
Main Success Scenario	1. User points mobile phone camera towards an electronic appliance 2. Application identifies appliance 3(a). If appliance needs to be activated, system displays Turn On virtual button 3(b). If appliance has already been activated, system displays Turn Off virtual button

Table 4.3: Scan Surrounding Use Case Scenario

Use Case Name	View Energy Consumption
Context	Display energy consumption of an electronic device in use
Actor	User and Application
Precondition	Application is running, user has selected Scan button and has scanned his/her surroundings, system has identified appliances
Post Condition	Energy consumption of an appliance in use is displayed
Main Success Scenario	1. User presses the Scan button 2. User points the camera view to an electric appliance in use 3. System identifies the appliance 4. If appliance has been registered, the system displays the energy consumption of the appliance depending on the time it was in use 5. System opens a popup window to display tips to the user 6. System closes popup window after user presses ok button

Table 4.4: View Energy Consumption Use Case Scenario

Use Case Name	Display Tips

Context	Tips need to be displayed
Actor	Application
Precondition	Application is running, user has logged on, user has selected Scan menu, system has identified an appliance
Post Condition	One tip is displayed to the user
Main Success Scenario	1. System identifies an electronic appliance 2. If energy consumption of the appliance is high, a popup window appears displaying one tip to reduce energy consumption for that device. 3. System can display up to three different tips randomly for each device

Table 4.5: Display Tip Use Case Scenario

Use Case Name	View Help
Context	View information on using the application
Actor	User
Precondition	Application is running, user has logged in, user has selected the Help menu
Post Condition	Help screen successfully displayed
Main Success Scenario	1. User presses Help menu 2. System opens screen showing instructions on how to use the application

Table 4.6: View Help Use Case Scenario

Use Case Name	Identify Appliances
Context	Electronic appliances in user surroundings need to be identified and recorded on local storage
Actor	Application
Precondition	Application is running, user has logged in, user has pressed Scan menu
Post Condition	Electronic appliances in use by user are successfully identified
Main Success Scenario	1. When user points mobile phone camera towards an appliance, system should recognize the appliance by comparing with existing image target files stored on database 2. If appliance matches the existing files, system display the Turn ON/OFF virtual button

	3. System records the identified appliance for energy consumption tracking

Table 4.7: Identify/Record Appliances Use Case Scenario

Use Case Name	Record time usage of appliance
Context	Time for which an appliance is in use should be saved by system
Actor	Application
Precondition	Application is running in background, system has identified and saved appliance
Post Condition	Duration of use of appliance successfully recorded and displayed on application
Main Success Scenario	1. System identifies electronic appliance 2. User has pressed Turn on virtual button 3. System starts recording the time duration during which the appliance is in use 5. User has pressed the Turn off virtual button 6. System stops recording the time 7. System display time duration in Energy menu

Table 4.8: Record Time Usage of Appliance Use Case Scenario

Use Case Name	Assess Quiz Answers
Context	Verifying the answers of the quiz questions
Actor	Application
Precondition	User has selected the quiz menu, and selected one answer from the four options provided
Post Condition	Message displayed to indicate whether user selected the correct or the wrong answer
Main Success Scenario	1. User has selected one answer 2. System compares the answer to the pre-defined correct answer 3. If both answers match, application displays correct message and move to next question 5. If both answer do not match, application displays wrong message and displays the Try Again button

Table 4.9: Assess Quiz Answers Use Case Scenario

4.2.3 Class Diagrams

A simplified class diagram representing the main classes of the system is shown in Figure 4.7.

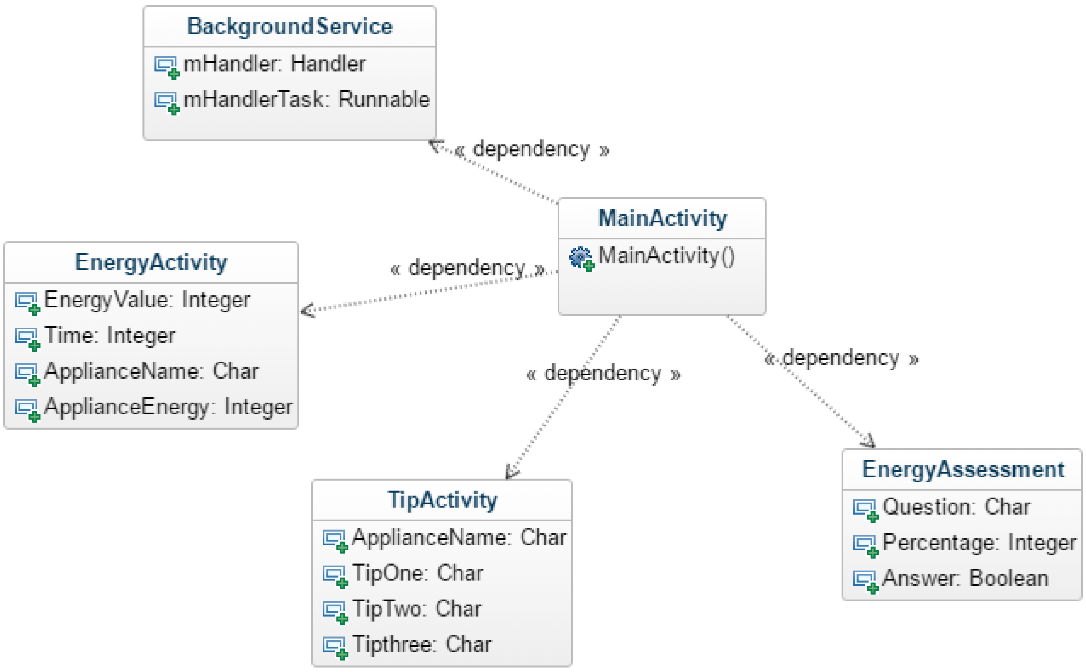


Figure 4.7: Class Diagram

Each class which has the suffix Activity represents a screen of the mobile application. For example, EnergyActivity.class and TipActivity.class are the login and register screens respectively. The diagram shows the relationships (dependencies) between the classes. When an activity class depends on another activity class in the design, it means that the independent class is called by the depended class.

4.2.4 Sequence Diagrams

A sequence diagram is used to show the interactions between objects in the sequential order that those interactions occur. Thus, with a sequence diagram it is easier to understand the data and messages flow between user and application.

The sequence diagram for the Display Energy Consumption of an appliance is shown In Figure 4.8. When the user opens the Scan menu, the server identifies the electronic appliance by highlighting the device. If the appliance was turned on, the server send the energy consumption value of that appliance, along with a tip if ever the appliance has consumed more than average electrical energy.

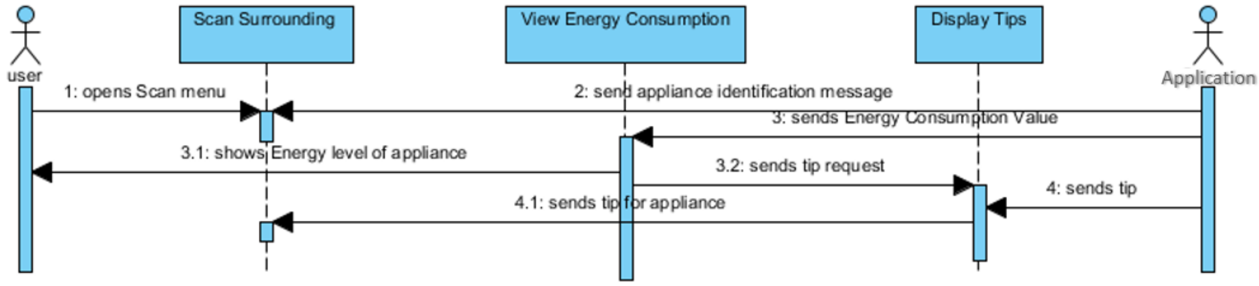


Figure 4.8: Display Energy Consumption of Appliance Sequence Diagram

4.2.5 Database Structure

The application will be using the local storage of the mobile devices to store data about the energy consumption and time duration of electronic appliances used. These data will be stored in xml format. The table below shows the attributes that will be stored on the xml file:

Attribute	***Description***
Appliance	The name of the appliance used
Energy	The amount of energy consumed for a period of time
Minutes	The number of minutes the appliance was in use
Seconds	The number of seconds the appliance was in use

Table 4.10: Attributes Stored in XML Document

The information described in Table 4.10 will be used to keep track of the energy consumption of users. When the user starts using any appliance, the appliance will measure the energy consumption and time duration during which the appliance was in use. Then these figures will be stored in and XML document and displayed on the Energy menu screen.

4.3 Chapter Summary

In this chapter, the design of the AR mobile application to raise awareness on green consumption of electronics has been described. Firstly, the functional and non-functional requirements of the application were outlined so as to understand how the application will meet the main objective of the project. The specific features were described, followed by an architecture diagram to give a high-level representation of how the application will function. Afterwards, wireframes of the application were designed. The functionalities of the application were visually defined with the use of specific mobile application design patterns. Use case diagram and use case scenarios were also outlined to further explain the functions of the application and how these will work. Class and sequence diagrams were also designed so as to shown in detail how the system will work.

Chapter 5– Implementation and Testing

In this chapter, the implementation of the application as well as the device database will be presented. In the first section, the application development will be discussed, as well as the tools and AR targets used. In the second section, the device database will be presented. The last section discusses the testing of the functional requirements and the non-functional requirements respectively. The UI testing of the application will also be presented.

5.1 Application Development

In this section, the implementation of the Android mobile application will be presented. Based on the design described in Chapter 4, the implementation techniques will be discussed, in addition to the image targets used and the energy consumption and efficiency measurement.

5.1.1 Tools and Libraries Used

Before choosing the tools to use to develop the application, a comparative study was made of the different available Augmented Reality SDKs. Among the different SDKs analysed are Vuforia, Wikitude, ARToolkit SDK and Beyond Reality's In2AR SDK. These were among the main SDKs considered during the analysis. These SDKs were chosen among a list of other available SDKs for review due to their popularity and AR performance. The features which were investigated were the ability of the SDKS to perform image and 3D object tracking effortlessly and to support a wide range of mobile devices. At the time of the review, Wikitude was in its early stages of 3D object tracking development, and offered only a trial beta version, which was not suitable for the development of this project. ARToolkit and Beyond Reality's In2AR SDKs did not support complex 3D object recognitions, but only basic objects like squares and cylinders. Vuforia, on the other hand, supports both image and 3D objects such as toys, computer parts and any other table-top objects. As such, Vuforia was the preferred choice for the development of the application. The implementation of the Android application was done entirely in Unity (version 5.0.0f4) and the Vuforia plug-in was used. All the tools that are needed to create the mobile application are available in the Unity software. Unity is a cross-platform game engine which was developed by Unity Technologies and allows for one-click deployment to a full range of platforms like mobile, desktop, VR, web, console and TV. Unity is also very intuitive to use and very customizable. Additionally, the rendering power as well as the optimized physically-based shading allow for the making of fast and powerful games and 3D applications (Unity Technologies, 2016). As such, Unity was considered to be one of the best platform for the development of an AR application. To be able to develop the AR feature of the application, Qualcomm's Vuforia Augmented Reality SDK was used. Vuforia is supported by Unity game engine to develop both Android and iOS mobile applications. The SDK is free to use, has robust development options and its AR extension allows developers to develop AR applications using Unity. Vuforia also uses a target manager which allows different target types, for example images and 3D objects to be uploaded in a database for use during development.

5.1.2 Image Targets Implementation

As discussed in Chapter 4, the AR mobile application should be able to detect various electrical and electronic devices available in both homes and offices. Since Vuforia AR SDK only detects specific image targets and small table-top 3D objects, a list of different image targets representing electrical and electronic appliances was created. The list of electrical appliances is based on the chosen taxonomy described in Section 3.3. Since there are various limitations with using large 3D objects, only pictures of the various appliances were used. The limitations with large 3D object tracking were related to the inability of Vuforia SDK to track and identify many calibration points with appliances such as refrigerators or washing machines. Moreover, most of these appliances have shiny textures, and this also affected the tracking process. As such, it was not possible to implement marker-less tracking for the electrical appliances. As such, the application developed was marker-based only. The sizes of the images targets vary per appliance. For smaller appliances, like a laptop, an image of approximately 1cm x 1cm was used. But for larger appliances, especially if these are fixed at longer distances (greater than 2m), larger image targets were used (approximately 4cm x 4cm).

5.1.2.1 List of Targets

The list of electrical and electronic appliances which are tracked by the application is shown in Table 5.1. The corresponding image targets used are shown as well. The main criteria for choosing the images was a good contrast in colours and patterns to enable the Vuforia plug in to recognize the images more easily.

 Lighting	 Vacuum cleaners	 Notebook Computers	 Battery Charger

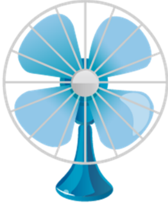
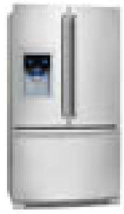
 Hair dryer	 Fan	 Air conditioners	 Refrigerator
 Microwave Oven	 Induction cookers	 Laser printer	 Washing machine
 Kettle	 CD Player	 Projector	 Electric Oven
 Gas Oven	 Dishwasher	 TV	 Coffee maker

Table 5.1: Image Targets Representing Electrical Appliances Used in Application

5.1.3 Energy Efficiency Assessment

The energy efficiency measurement is implemented to provide the user with an estimate of how much they adopt an eco-friendly approach while using their electrical and electronic devices. To be able to determine this, a list of questions is displayed to the user. The questions are close-ended questions, with Boolean type answers (Yes/No). The questions asked to the users are related to the best practices while using the individual appliances. The list of best practices for all the appliances were described in section 3.4 of the report. The choice of basing all the questions of best practices related to the appliances enables a better understanding on how much the users adopt energy efficient behaviours and practices while using electrical appliances. This enables a close estimate to the extent to which users are eco-friendly. The answers to the questions are then aggregated to determine an approximate percentage of the energy efficiency measure of the user. In the application, the energy efficiency measurement is represented by a colour-coded figure. The colour-coded figure was derived from European Union energy label, where green represents the most energy-efficient appliance and red the least efficient. Orange, being closer to red, is least energy-efficient than the yellow colour. Only four colours were used to equally represent 25% on a scale of 100%. This is illustrated below:

- If 0-25% of the answers are correct, it means the user has the lower energy efficiency measure and is indicated by a red figure ().
- If 26%-50% of the answers are correct, it means the user has a moderate but below average energy efficiency measure and is indicated by an orange figure ().
- If 51%-75% of the answers are correct, it means the user has a moderate but above average energy efficiency measure and is indicated by a yellow figure ().
- If 76%-100% of the answers are correct, it means the user is very energy efficient and is indicated by a green figure ().

The percentage number is also indicated on the interface.

5.1.4 Energy Consumption Measurement

One of the main purpose of the application is to give the user an estimate of the amount of energy consumed by their electrical and electronic appliances usage. To be able to achieve this, the AR extension of Vuforia is used. Each appliance is represented by a specific image as shown in Section 5.1.2.1. All the images are then uploaded and converted into recognizable image targets through the Target Manager on Vuforia developer website. This means that Vuforia Target Manager converts the image into a suitable format to allow the plugin to detect and track the image markers. The targets are all grouped within a single dataset, which is then downloaded as a Unity package. The respective license code is also copied from the target manager and inserted in the Unity application environment. During the development, the dataset is imported into Unity in order to configure all the image targets.

Each image target is assigned a specific power (in Watts) value based on the type of appliances. This value is the power rating and varies for different appliances. The power rating was determined for all the appliances to be augmented by searching for the average power consumption values via an online search. The set of energy efficiency questions also different for the image targets.

To calculate the energy consumption value, the following formula has been used:

Energy Consumption (in kWh) = Power (Watt) * Time (hour) / 1000

The energy consumption value is given in kWh, and the time during which the appliance was in use are also indicated on the interface. To start measuring the energy consumption of an appliance, the user needs to ensure that the electrical appliance is switched on in their real environment. Immediately after, the user needs to press the switch “ON” button in the mobile appliance to start the timer and measurement of the energy consumption. When the user switches off the appliance in their environment, the person should also press the “OFF” virtual button to stop the timer and obtain the energy consumption value. The switch buttons in the application are further described in the next section of the report. This value is obtained by multiplying the timer value and the default power value of the appliance.

5.1.5 Graphical User Interface Implementation

The user interface was designed in Unity, using both the GameObject-based interface design feature of Unity and the Immediate Mode GUI (IMGUI) scripting API. With the GameObject-based feature, it was possible to add different user interface elements (Game Objects) such as buttons, canvas, labels and texts by selecting the required components and placing them on the application screen. The IMGUI monobehaviour in Unity is mainly code-driven and allows for rendering and handling of Graphical User Interface events. It was used mainly while creating the interface for the AR View menu. The GameObject-based UI was used to design the other menus.

In the application, there are five different menus, which are described below:

1. AR View: This menu allows the user to access the AR feature and to scan their environment. The menu opens a camera-view by accessing the device’s camera feature, and thus allowing the users to scan their environment to activate any electrical appliance in use. Using this menu, users are able to track the appliances in use and measure their energy efficiency.
2. Energy: This menu allows the user to view a list of all the appliances in use, along with the total energy consumption.
3. Quiz: This menu contains a list of twenty questions for users to answer and test their knowledge on eco-friendly habits.
4. Setting: The setting menu allows the user to turn the sound on and off.

5. Help: As mentioned in Chapter 4, this menu aids the user to navigate through the application.

Figure 5.1 shows an example of a menu created, which is the main menu. The main menu allows users to select different sub-menus to achieve different tasks.

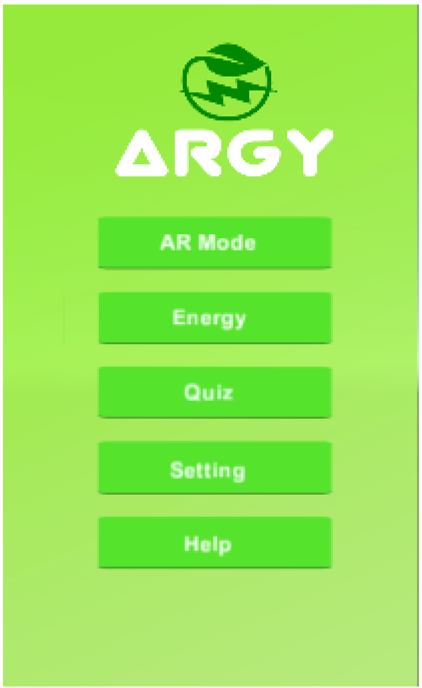


Figure 5.1: The Main Menu Screen

Figure 5.2 shows another example of a sub-menu, which is the quiz menu. The user is presented with each question one at time, along with four different options to choose from. To go to the next question, the user needs to select the “Next” button.

Figure 5.2: One Screen from the Quiz Menu

After selecting the ARView menu, the application launches the camera view of the mobile device and the user needs to scan the image target corresponding to the electrical appliance in use. When the application detects the image of the electrical appliance, the following screen appears:

Figure 5.3: ARView Screen when Projector is detected

When the application detects the image target corresponding to a projector for example, a digital overlay appears as shown in Figure 5.3. The text "Projector Detected" appears at the top of the screen to indicate to the user that the specific appliance has been detected by the application. The name of the appliance changes based on the type of appliance detected. On the left of the image target are the four buttons mentioned in Chapter 4, namely the Switch button, Energy button, Tips button and Home button. The Switch button is in the OFF state when the application detects the appliance for the first time.

Figure 5.4: Switch Button is Turned ON

Figure 5.4 shows the Switch button changed from the "OFF" state to the "ON" state when the user touches the switch button to start measuring the energy consumption of the projector. After using the appliance, the user needs to touch the Switch button again to stop the application from continuing to record the time and energy consumption of the appliance. On selecting the Switch button again, it goes to the OFF state and the energy consumption and time duration during which the appliance was in use are shown on the mobile screen, as shown in Figure 5.5.

Figure 5.5: Energy Value and Time Duration Displayed on Screen

In order to assess their energy efficiency, users need to select the Energy button and a series of questions will be displayed on the screen. The questions are related to the appliance. One example is shown in Figure 5.6 and Figure 5.7 below:

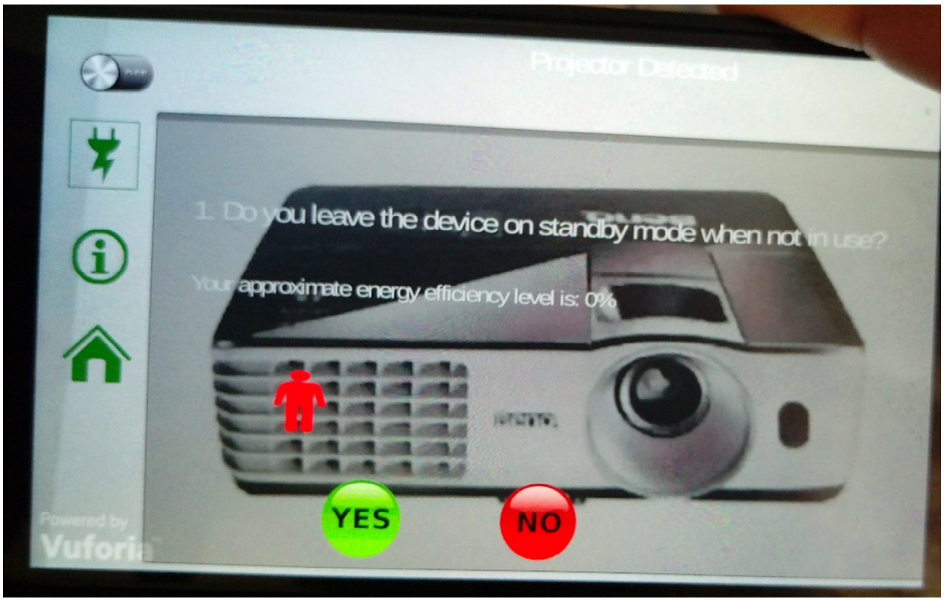


Figure 5.6: Energy Efficiency Assessment

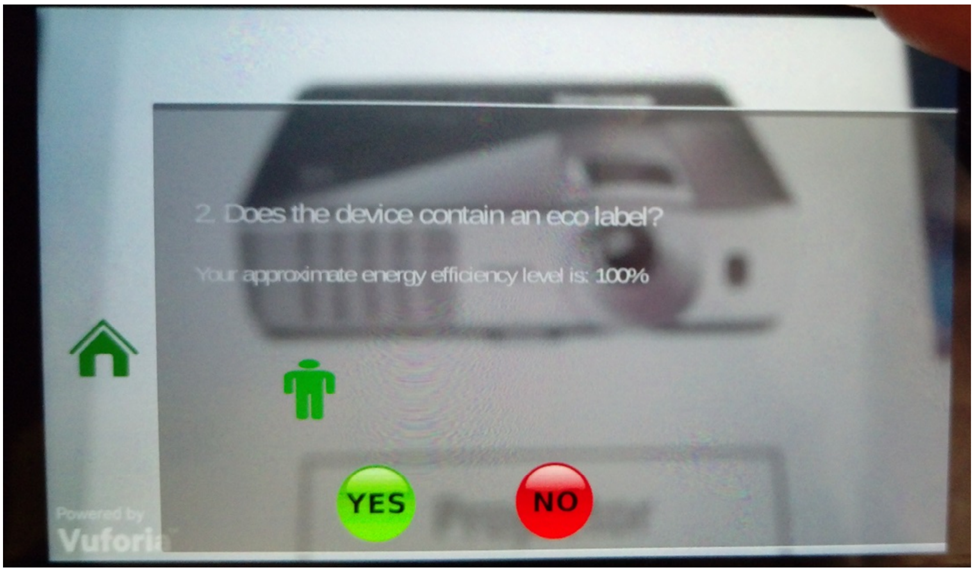


Figure 5.7: Energy Efficiency Assessment

As seen in both Figure 5.6 and 5.7, different questions are asked to the user to determine their energy efficiency percentage. Users need to only answer with a “Yes” or “No” by touching on the Yes and No buttons respectively. The energy efficiency percentage is also calculated and displayed depending on the users’ answers. Furthermore, the small man icon is used as a visual indication of how energy efficient the users are. In Figure 5.6, the energy efficiency level was 0% and as such the man icon was red. In Figure 5.7, the man icon was green since the energy efficiency level was shown to be 100%.

Another feature in the ARView menu is the Tip button, which shows different tips for the appliances. One example for the coffee maker appliance is shown in Figure 5.8 below:

Figure 5.8: Tips Displayed for Coffee Maker Appliance

5.2 Implementation Challenges

During the application development, several challenges were encountered. The challenges faced are described below, along with how these were resolved.

- The first major challenge faced in this research study is the unavailability of a commercial Augmented Reality SDK for 3D objects. For this project, it was preferred for the mobile application to be able to detect electrical appliances, especially large ones such as refrigerators or washing machines. However, none of the AR SDKs investigated at the time of the research provided such a feature with great accuracy and efficiency. It was thus not possible to use the markerless AR feature. In order to overcome this challenge, the markerless approach was replaced with the marker-based approach, whereby different image markers were selected to represent the electrical and electronic appliances. Those image markers were then printed and used as a means of detecting the appliance for augmentation.
- The second difficulty encountered during the development stage was recording the time duration and energy consumption during which an appliance was in use. The Vuforia SDK was developed in such a way to reiterate the image target detection process every time the application detected a particular image marker, and thus making it difficult to use the Switch button. This problem was solved, whereby it was possible to save the time duration and energy consumption values on a local text file, and display these values in one of the application menus by modifying the codes.
- Another challenge encountered was the determination of the energy efficiency level of the application users. Initially, it was proposed that a quantitative approach would be used and to rank the energy efficiency level on a set scale. To achieve this, it was necessary to compare the energy consumption value of the users for an appliance with the acceptable energy-efficient consumption value for that same appliance. This means that if an appliance is consuming a certain amount of electrical energy which is considered to be an energy-efficient value, then if the electrical energy value consumed by the user for that appliance is below the acceptable green electrical energy value, then the user is considered to be energy efficient. The issue with this approach is it was not possible to determine the exact acceptable green electrical energy consumption of the individual appliances. Such figures were not available for all the devices used in the application. As such, a different qualitative approach was considered. For this one, the users were asked a set of questions related to how they use the different appliances and the various green practices they adopt. Based on the answers, an estimate percentage was determined to indicate to which extent the users were energy efficient.

5.3 Testing

In this section, the testing of the functional and non-functional requirements are described respectively. Most aspects of the application were tested during and after the implementation.

5.3.1 Functional Requirements Testing

Most aspects of the application was tested to meet the functional requirements described in Section 4.1.1. The following tables show the test cases written to evaluate the functionality of the application. East test case has a unique identifier.

Test ID	T1
Tested Requirement	F1 & F2
Test Content	Check that the application allows the user to scan their environment and detect electrical appliances
Input	User selects the AR View menu, and hover the device camera over an electrical appliance
Passing Criteria	The switch, energy efficiency, tips buttons should appear on the screen, along with the name of the detected electrical appliance.

Test ID	T2
Tested Requirement	F3 & F4
Test Content	Users must be able to activate and de-activate any electrical appliance tracking
Input	When user hovers the camera over an appliance, the switch button should appear to allow the user to start or stop tracking the appliance
Passing Criteria	If an appliance was already being tracked, the “OFF” switch button should appear, else if an appliance was not being tracked, the “ON” switch button should appear

Test ID	T3
Tested Requirement	F5
Test Content	When an appliance is tracked, the user should be able to view the energy consumed by the appliance any time the application detects the appliance

Input	The user touch on the "ON" button to start tracking the device, the timer is activated and the energy consumption of the appliance should be calculated based on the time during which the appliance is being tracked
Passing Criteria	The energy consumption should be displayed in KWh.

Test ID	T4
Tested Requirement	F6
Test Content	The user should be able to calculate an estimate of the extent to which the appliance is being used in an energy efficient manner. The result is displayed in the form of colour codes
Input	When an appliance is detected, the user select the Energy Efficiency icon. A list of questions appear for the user to answer. The user completes the list of questions
Passing Criteria	After answering all the questions, an estimate percentage is displayed to indicate how energy efficient the user is. Additionally, a colour-coded figure is shown to represent how much the user uses the appliance efficiently.

Test ID	T5
Tested Requirement	F7
Test Content	The application should display tips to users to enable them to save energy
Input	The user selects the tips icons when the appliance detects an appliance
Passing Criteria	A window containing three tips should appear on the screen after the user selects the Tips icon.

Test ID	T6
Tested Requirement	F8-14
Test Content	The application should be able to save the energy consumption and time duration of the appliances in use, and display these in the Energy menu
Input	The user selects the Switch button to start and stop measuring the energy consumption of an appliance and selects the Energy menu to view the energy consumptions of all appliances in use.

Passing Criteria	The energy consumption and time duration of the appliance being scanned is shown in ARView menu. When the Energy menu is selected, a list of all appliances in use, along with their energy consumption and time of use are displayed.

Table 5.1 shows the test results of all five test cases. All the functional requirements were met during the implementation.

Test Identifier	***Test Result***
T1	Pass
T2	Pass
T3	Pass
T4	Pass
T5	Pass
T6	Pass

Table 5.2: Functional Requirement Test Cases Results

5.3.2 Non-functional Requirements Testing

In this section, the non-functional requirements identified in section 4.1.2 are tested.

ID	***Description***	***Result***
NF1	The graphical user interface must be easy enough for anyone and all screens should have a similar style.	All the screens have similar designs and colour theme. The interfaces have been kept as simple as possible for easier navigation
NF3	The system must have lack of bugs and inform the user of every wrong operation.	The application has error messages in case the user misses any required operations. For example, if the user doesn't answer a question while measuring the energy efficiency, the user is notified via a popup window
NF5	The system will have fast response time.	The application has been tested during appliance tracking. The applications detects any image targets within less than 5 seconds, and the buttons are immediately displayed.

NF6	The system must be designed to be able to accept new operations and features.	New image targets can be easily added to the current dataset via the Target Manager on Vuforia website. Similarly, Unity provides an easy interface to edit the UI or add new features without necessarily having to edit the current codes.
NF7	The system will be able to run on all Android devices.	The application has been tested on different Android devices, with different screen sizes. Some minor errors have been found in the screen layout, such as the buttons on the main menu are not all of the same size in larger screens. This have been rectified.

5.4 Chapter Summary

This chapter describes the development phase of the application. It started with a description of the development platforms used, that is Unity and Qualcomm's Vuforia AR plugin. Afterwards, the list of image targets used to track the electrical and electronic appliances were presented. The different features developed were also described, along with examples of some of the menus created. The last part of the Chapter consisted of a description of the functional and non-functional testing performed during and after implementation.

Chapter 6– Evaluation Method

In the previous chapter, the implemented prototype was described along with the tests made against its requirements. In this chapter, the method used to evaluate the research question under investigation and the prototype will be described. Additionally, the data collection method, population sample used and experimentation setup will be described.

6.1 Evaluation Design

In this section, the evaluation design approach will be described. The approach consists of six main phases, as shown in Figure 6.1. The individual phases will be further described in the next sub-sections.

Figure 6.1: Evaluation Design Phases

6.1.1 Selection of Evaluation Approach

As discussed in Chapter 1 of this report, the main objective of this study is to understand the extent to which Augmented Reality can be effectively used to raise awareness on green consumption of electronic devices. This is according to the main research question of the project, which is:

"*Can Augmented Reality be effectively used as a mechanism to improve awareness on green consumption of electronic devices?*"

Based on the above research question, it was hypothesized that the use of Augmented Reality in the mobile application should reflect an increase in knowledge on the green practices associated with the use of electrical and electronic devices both at homes and offices. In order to assess whether there is an increase in knowledge from the users on green practices while using electrical appliances, it was necessary to have a pre-test and post-test design approach. The nature of the research was experimental, and as such it was necessary to have both independent and dependent variables. The learning method would serve as the independent variable and the learning gains from both pre-test and post-test evaluations would serve as the dependent variables. As part the study, it was also important to assess the level of acceptance and motivational influence the AR application had on the participants. As such, the Technology Acceptance Model (TAM) was used to achieve this objective. Technology acceptance is normally defined as the way by which people accept and perceive the use of technology. To address this, different models have been developed to measure how much users accept or are willing to utilize particular technologies. The TAM model was used for the purpose of this study because it was considered to be the most experimentally validated and widely used among all other models such as the Innovation Diffusion Theory or Unified Theory of Acceptance and Use of Technology (King & He, 2006). The TAM design model as suggested by Davis (1993) is depicted in Figure 6.2 below:

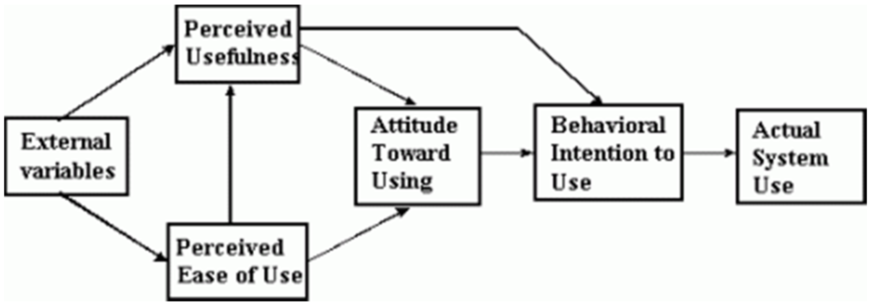


Figure 6.2: Original TAM design by Fred Davis
(Source: Davis, 1993)

Since most of user acceptance studies are dependent upon the technologies being analysed, the main TAM model is combined with other specific constructs which are applicable to the technologies being evaluated (Chesney, 2006). Constructs refer to weight related factors which help in assessing the use and acceptance of the technology. In this research, the level of enjoyment was considered as an important factor that possibly could have an effect on users' use of the technology. Over the years, this has become a common attribute employed in user acceptance research. Previous research from Davis (1989) also highlighted perceived usefulness and Ease of Use as equally important factors towards a positive effect on user motivation and technology acceptance. It was established that when users find a technology easy to use and believe it will improve their learning, they equally as a result intend to further adopt it in the future. Taking into consideration the factors highlighted, table 6.1 displays the chosen constructs that were used to establish the questionnaire design for evaluation.

Constructs	Definitions
Perceived Enjoyment	The level to which an activity carried out through the use of a particular technology is deemed enjoyable (Chesney, 2006).
Perceived Ease of Use	The level to which users of the system feel its use will be effort free (Davis, 1989).
Perceived Usefulness	The level to which users feel that utilizing the technology will aid in enhancing their task accomplishments (Davis, 1989).
Intention to Use	The level to which users have devised conscious intentions to utilize or not utilize certain specific future practices (Davis, 1989).

Table 6.1: Implemented Constructs Used for TAM Questionnaire

6.1.2 Design of Data Collection Instrument

The user evaluation was conducted through the use of three questionnaire designs. These were used to gather information from the selected participants. The information which will be gathered will be mainly quantitative related since the quantitative method approach allows for statistical analysis of the gathered data. Also, due to the nature of the study and the number of participants, the use of qualitative user evaluation methods such as one-to-one interviews would not have been proper or provided the level of accuracy and integrity as compared to the use of questionnaires. The questionnaires used are further described in the sub-sections below.

6.1.2.1 Multiple-Choice Questionnaires

The multiple choice questionnaire prepared for the pre-test and post-test experiments consisted of a set of 15 questions related to green practices and consumption of electrical and electronic appliances (Appendix A and B). The questions were mainly based on the tips given in the application, the quiz feature and energy efficiency ratings. Each question was assigned a total of four options, of which only one was the correct answer. The same set of questions was used for both the pre-test and post-test questionnaires, but the questions and answers were shuffled in a different order. The reason behind not changing the questions was to analyse whether the knowledge gains of the participants in the post-test experiment.

6.1.2.2 Technology Acceptance Model Questionnaire

The technology acceptance model questionnaire consisted of 18 questions to assess the learning and motivational influence of the participants (Appendix C). The questionnaire was made up of four sections, based on the four constructs specified in Table 6.1. In each of the constructs, the criteria were evaluated against a 5-point Likert scale, as follows:

1- Strongly Disagree

2- Disagree

3- Neutral
4- Agree
5- Strongly Agree

6.1.3 Targeting and Selection of Participants

According to Jakob Nielsen (2016), the minimum number of test users required for quantitative studies to obtain statistically significant numbers is 20. Based on this rule, a total of 40 participants were recruited to participate in this research study. All of the participants consisted of students and staffs from Middlesex University Mauritius Branch Campus. Since the research investigates the user groups from both households and offices, the students were chosen to represent the household user category and the staff members will represent the office workers category. 20 of the participants were undergraduate students and the other 20 participants were staffs from the university, both from the administrative and academic departments. The number of participants was determined based on the minimum number of test users required for quantitative usability test studies. The participants were directly approached and were briefly informed about the research study and procedure. The participants were also requested to specify the type of mobile devices/ tablets used and only those prospective participants owning an Android device were recruited. The participants were also asked to bring their devices for installation purposes. Those participants who agreed to be involved in the experiment were provided further details about the research study by means of electronic mails. The pre-test and post-test surveys were conducted on two separate days, with a one week interval in between.

6.1.4 Preparation for Data Collection

Before starting the data collection process, a pilot study was conducted to assess any potential issues which might occur in the final data collection phase. The questionnaires and the mobile application installation file were given to two staff members of Middlesex University Mauritius Branch Campus to be evaluated. The staff members were asked to fill-in the pre-test questionnaires and then install the application on their Android devices. After using the application for two days, they were asked to complete the other post-test and TAM questionnaires. After completing this process, the staff members were asked to give their feedback on the evaluation method. Both of them approved of the method and found no major problems with the way the evaluation was conducted. Minor changes were made in terms of rephrasing some questions for better understanding.

6.1.5 Data Collection

The experiment consisted of three main phases. The first phase of the experiment consisted of the pre-test experiment. Since it was not possible to gather all the participants on the same day due to the busy schedules of the staff members, this exercise was spread out in two days. The pre-test experiment required the participants to fill-in the first multiple-choice questionnaire to assess their current knowledge on green electrical energy practices. Before that, all the participants were briefed on the purpose of this experiment and the intended objectives. All the forty participants filled in the questionnaires and immediately returned these to the investigator. It was important to ensure the participants did not verify their answers before submitting the questionnaires.

The second phase of the research study consisted of the installation of the AR mobile application on the mobile devices of the participants. On the same day the participants submitted the first pre-test questionnaires, they were given the apk file of the ARGY mobile application. The investigator ensured the application was properly installed on their devices and was running perfectly. The participants were then asked to use the application for a week. Due to the time limit of the research project, a period of one week was deemed sufficient for the participants to use and understand their energy consumption of electrical devices and learn the different green energy practices. The participants were informed on how to use the mobile application, especially on how they were supposed to use the AR feature of the application with their appliances. Additionally, all the image targets were printed and cut into square pieces. The participants were told to either place the image stickers next their electrical appliances, or stick them on the appliances if possible. They were instructed to use the AR feature of the application every time they were using the electrical appliances corresponding to the image targets and to track their energy consumption. After the successful installation of the applications, the investigator informed the participants that the third and last phase of the experiment would be conducted after a week.

The third phase of the experiment consisted of assessing the knowledge gains of the participants after using the application and their motivational influence for using the application again. After a week, all the participants were contacted again by email so as to fix a session for conducting the last activity. This phase was again conducted over a two-day period so as to ensure that all the participants were given the same amount of time to use the mobile application since the day they completed the first activity. During that phase, the participants were given the same multiple-choice questionnaire used in the pre-test experiment, but this time the questions were shuffled. The participants were asked to fill in this post-test questionnaire, and not to use the application while answering the questions. The aim of this activity was to evaluate the knowledge gains of the participants after using the application for a week. After completing this activity and submitting the questionnaires to the investigator, the participants were given the TAM questionnaires to complete. They were briefed on the purpose of this questionnaire.

Once this exercise was completed, the participants were thanked for their full participation in the experiment, and were given the contact details of the researcher in case they needed any further information about the research.

6.1.6 Data Analysis

After obtaining the completed questionnaires, the next phase of the evaluation was data analysis. To analyse the data obtained from the three set of questionnaires, SPSS Statistics was used to make the statistical analysis since it is the most widely used program. The different questions asked and criteria used in the TAM questionnaire were represented by specific variables to facilitate the analysis process. Those variables were used to generate the results, which consisted of graphs and other statistics relevant to this research.

6.2 Experimentation Challenges

During the evaluation phase, a few challenges were encountered. These are described below:

- The busy schedules of the staff members made it difficult to conduct the pre-test analysis on the same day. As such, this phase was spread into two different days depending on the availability of each staff member. It was ensured that all the staff participants were given a full week to use the application and this was done by noting which staff members completed the pre-test questionnaire on the first day and which members did the same process on the second day. The post-test questionnaires and TAM questionnaires were also filled over a two-day period.
- Another technical difficulty faced by some of the participants was the fact that the application caused their mobile devices to overheat a lot. This forced the participants to stop using the application for some hours and then re-use it again. This issue was also encountered during the development stage and unfortunately could not be overcome. This is mainly because the mobile application was constantly using the camera feature of the mobile devices and hence was using a lot of processing power and battery life.

These were the two main challenges faced during the evaluation phase. Apart from these two, no other major difficulty was faced by the participants and the evaluation was successfully completed.

6.3 Chapter Summary

This chapter described the methodology of the research study. The user evaluation conducted was described, and details were given on the different phases of this activity. The user evaluation method chosen was justified, and an overview was given on the participants recruited. The questionnaires used during the evaluation were outlined in detail. Each phase of the evaluation study was properly described as well. The pre-test and post-test approach allowed for the third objective of this research study to be met, which was to analyse to which extent AR can improve the learning process on green consumption of electronic devices.

Chapter 7– Results and Discussions

In this chapter, the findings of the user evaluation will be discussed. The discussion consists of both an analysis of the pre-test and post-test design, along with the findings from the Technology Acceptance Module questionnaire.

7.1 Technology Acceptance Model Results and Analysis

The following sub-sections discusses the results from the technology acceptance questionnaires. The four different constructs are analysed in detail.

7.1.1 Perceived Enjoyment Results

The results from the analysis of the perceived enjoyment results are shown in Table 7.1. 57.5% of the participants agreed that the AR application was fun to use, while 25% of the participants were neutral on this criterion. A majority of 52.5% of the participants either agreed or strongly agreed that the application was pleasant. However, when asked on whether they feel a high level of enjoyment using the system, 42.5% of the participants remained neutral while 27.5% and 5.0% agreed and strong agreed respectively. Only 15% of the participants were unhappy that experience was over, while 42.5% remained neutral. However, majority of the participants (62.5%) are willing to repeat the same experience, and 67.5% of the participants found the experience interesting.

Criteria	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
The AR application is fun to use.	2.5%	15.0%	25.0%	55.0%	2.5%
The AR application is pleasant.	2.5%	15.0%	30.0%	40.0%	12.5%
I feel a high level of enjoyment using the system.	5.0%	20.0%	42.5%	27.5%	5.0%
I feel unhappy the experience is over.	2.5%	40.0%	42.5%	12.5%	2.5%
I am willing to repeat the same experience.	0.0%	12.5%	25.0%	57.5%	5.0%
This was an interesting experience.	2.5%	15.0%	15.0%	52.5%	15.0%

Table 7.1: Perceived Enjoyment Results

7.1.2 Perceived Ease of Use Results

The results for the Perceived Ease of Use construct are shown in Table 7.2. Most of the participants, 65%, either agreed or strongly agreed that learning to use ARGY application was easy. Only 2.5% disagreed and 2 participants mentioned they found the application difficult to use. 35% of the participants found it easy to navigate through the different menus. Most of the participants, 75%, agreed that it was easy to get used to the application. Finally, 42.5% agreed and 20% strongly agreed that the application was easy to use.

Criteria	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
Learning to use ARGY application is easy.	0.0%	2.5%	32.5%	52.5%	12.5%
I found it easy to navigate and select the different options in AR View menu.	0.0%	12.5%	52.5%	32.5%	2.5%
It was easy getting used to the AR energy application.	0.0%	10.0%	15.0%	62.5%	12.5%
Overall I found the application easy to use.	2.5%	12.5%	22.5%	42.5%	20.0%

Table 7.2: Perceived East of Use Results

7.1.3 Perceived Usefulness Results

The results for Perceived Usefulness can be seen in Table 7.3 below. According to the findings, 65% of the participants agreed or strongly agreed that the application would help keep track of their electrical energy consumption more effectively. 55% of the participants agreed or strongly agreed that the application enhanced their awareness on green consumption of electrical devices, while only 10% disagreed with this. 40% of the participants are neutral to the fact that the application would help reduce the electricity bill, while 47.5% are favourable to this statement. Lastly, 52.5% of the participants found the technology a useful learning tool.

Criteria	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
Using the application would help track my electrical	0.0%	7.5%	27.5%	57.5%	7.5%

energy consumption more effectively.					
Using the application would enhance my awareness on green consumption of electrical devices.	0.0%	10.0%	35.0%	47.5%	7.5%
The application will help reduce my electricity bill.	0.0%	12.5%	40.0%	45.0%	2.5%
I find AR technology a useful learning tool.	0.0%	17.5%	30.0%	50.0%	2.5%

Table 7.3: Perceived Usefulness Results

7.1.4 Intention to Use Results

The results for Intention to use the technology are shown in Table 7.4 below. In general, there is a positive response to using the application. 45% of the participants are attracted by the AR technology while 30% are neutral. 47.5% intend to use AR related application to increase their knowledge on green consumption of appliances. Finally, 67.5% of the participants expressed their intention to use the application provided they had access to it.

Criteria	***Strongly Disagree***	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***
I intend to use any system attributed to AR technology when it becomes commercially available	0.0%	25.0%	30.0%	37.5%	7.5%
I intend to use other related AR application to increase my knowledge on green consumption of appliances.	0.0%	15.0%	37.5%	42.5%	5.0%
Given that I had access to the application, I predict that I would use it frequently.	2.5%	12.5%	32.5%	47.5%	5.0%
Assuming I had access to the application, I intend to use it.	0.0%	0.0%	32.5%	57.5%	10.0%

Table 7.4: Intention to Use Results

7.1.5 Critical Analysis

In order to further investigate the adoption of the application, the relationship between knowledge gain and intention to use the application was also investigated. The result is shown in Table 7.5. Out of the 21 participants who agreed that the application would enhance their awareness, 14 and 4 agreed and strongly agreed that they would use such an application given access to it. This is quite a positive result and shows that the AR technology does help in raising awareness on green consumption practices. Overall, 40% of the users were happy while using the application, and the rest did not report any specific features which could have prevented them from enjoying usage of the application. This result also correlates with the Perceived Ease of Use results, which were mostly positive. Most of the users found the application to be easy to learn and use, and encountered no major difficulties with any of the features of the application. These results are further supported by the fact that more than half of the users found the whole experience to be interesting, hence indicating a positive adoption of Augmented Reality in everyday activities. Most of the users also find the application to be useful, and agree that it would help them reduce their energy consumption. The results for users who find the application more effective in tracking their energy consumption and those who find AR a good learning tool are quite similar, hence signifying that AR had a positive impact on the learning process of the users. Users found AR to be a useful tool in helping them track their energy consumption and did not reject the technology. Furthermore, the participants demonstrated a further interest in AR technology as a learning tool, since most of the users express an interest in using AR to further increase their knowledge on green practices and efficiency. More than half of the participants also agree that they would use the application, thereby indicating a positive adoption of the prototype mobile application, along with its AR technology.

Count

		Assuming I had access to the application, I intend to use it.			Total
		Neutral	Agree	Strongly Agree	
Using the application would enhance my awareness on green consumption of electrical devices.	Disagree	3	1	0	4
	Neutral	5	8	1	14
	Agree	5	11	3	19
	Strongly Agree	0	3	0	3
Total		13	23	4	40

Table 7.5: Relationship between Awareness on Green Consumption of Electrical Devices and Intention to Use the Application

7.2 Results from Pre-test and Post-test Experiments

As discussed in the previous chapter, one of the objectives of the study was to evaluate to which extent Augmented Reality can be used to improve the learning process on green consumption of electronic devices. To better illustrate this, a detailed analysis of the results from both pre-test and post-test questionnaires was done. This is described in the following sub-sections.

7.2.1 Understanding of the term kilowatt-hour

The result for the participants' understanding of the definition of the term kilowatt-hour is shown in Figure 7.1. The answer to this question is "All of the above". As seen on the chart, most of the participants, 31 in total, got the right answer in the post-test experiment. This figure is much higher compared to the 14 participants who obtained the right answer in the pre-test questionnaire.

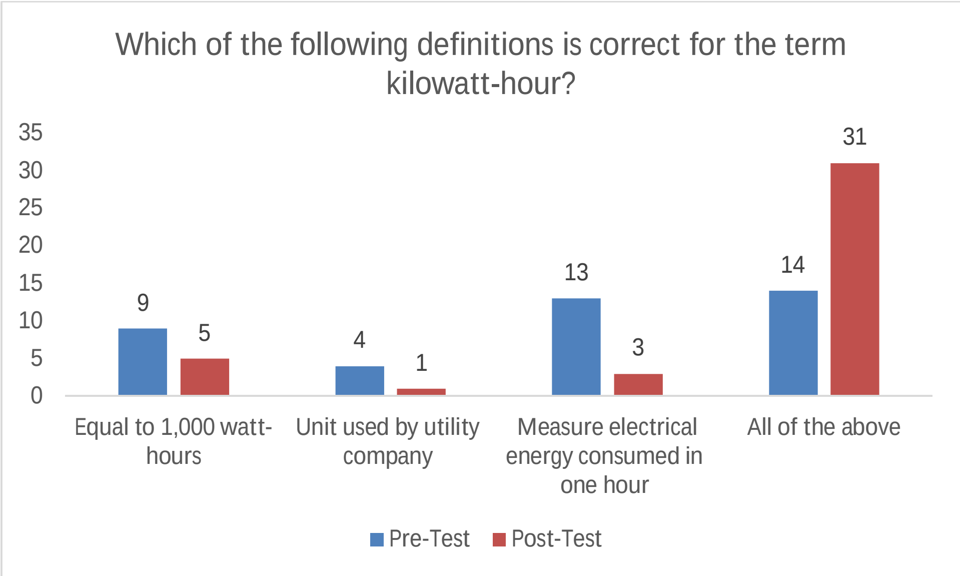


Figure 7.1: Result for Definition of the Term Kilowatt-Hour

7.2.2 Best practices when using electric ovens

The participants were asked about their understanding on the use of electric ovens. The results are shown in Figure 7.2 below. For this question, all three answers are true. The results shown that both in the pre-test and post-test experiments, most of the participants got the right answer. Nevertheless, there was a major improvement in the post-test result, with an additional 14 participants getting the correct answer as compared to the 17 participants in the pre-test result. This outcome is positive since it shows that the application aided the participants to better understand the use of electric ovens.

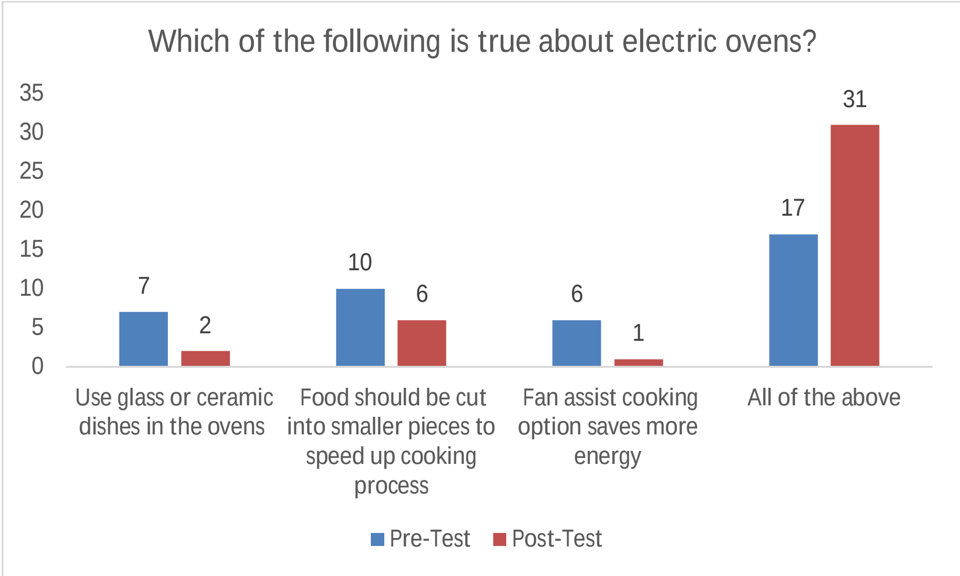


Figure 7.2: Use of Electric Ovens

7.2.3 Understanding of the electrical energy waste due to using standby mode

For this question, the answer was "4 hours viewing time". As seen in Figure 7.3, in the pre-test experiment, most participants (33) were not aware of this information. Only 7 participants obtained the right answer. However, in the post-experiment, this figure increased to 25, which shows a significant gain in knowledge on this particular question.

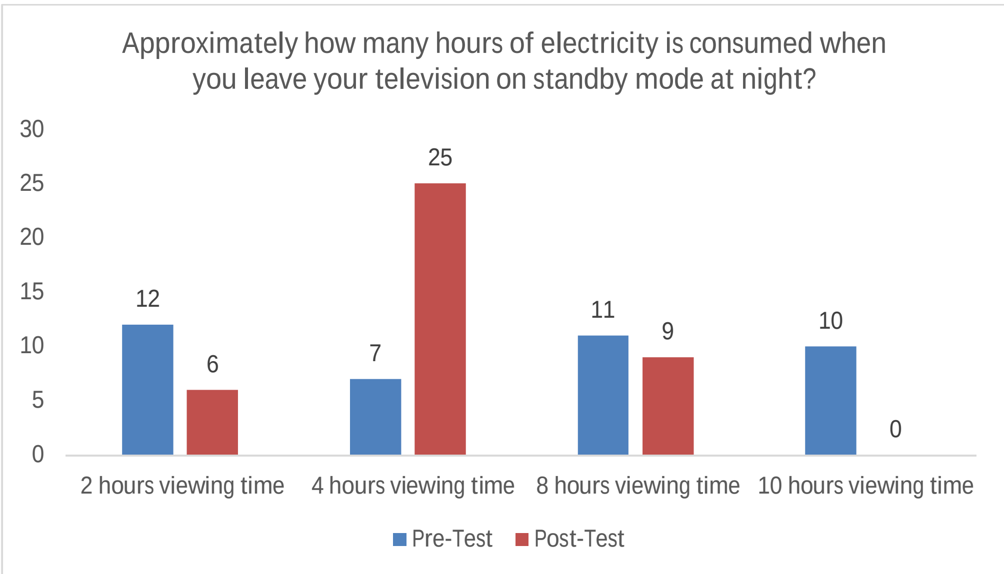


Figure 7.3: Electrical Energy Waste when Television is Left on Standby Mode

7.2.4 Energy-saving type of bulb

The most energy saving type of bulb among the four options given is the Light Emitting Diodes. In both the pre-test and post-test experiments, most of the participants chose the correct answer, as shown in Figure 7.4 below. The figure increased from 20 to 36 in the post experiment questionnaire.

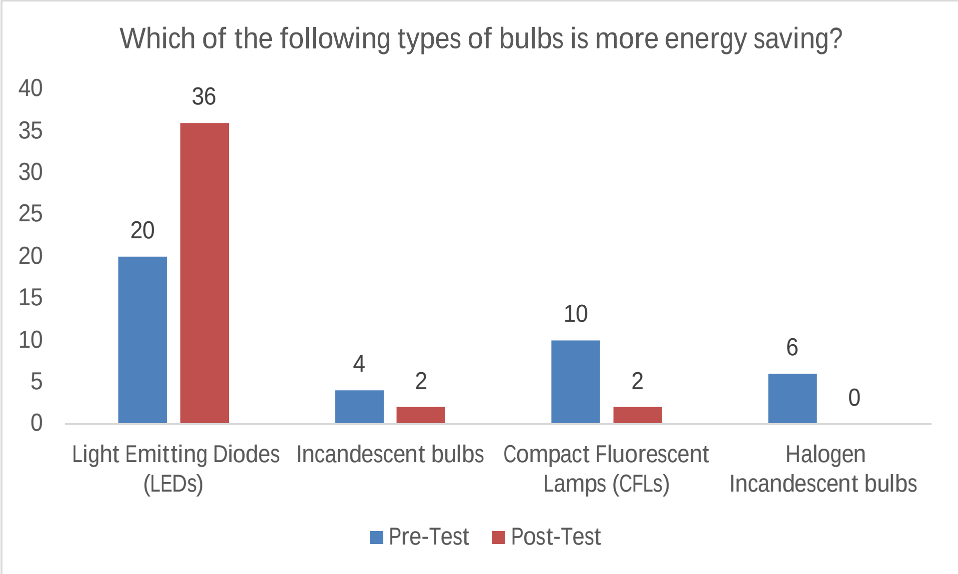


Figure 7.4: Energy-saving Bulb Type

7.2.5 Heat Loss in Oven Use

The participants were asked approximately how much heat was lost when the door of an oven is opened while it is in use. The answer to this question is 20%. Even if 15 of the participants still did not obtain the correct answer in the post-test experiment, 25 of them got the right answer.

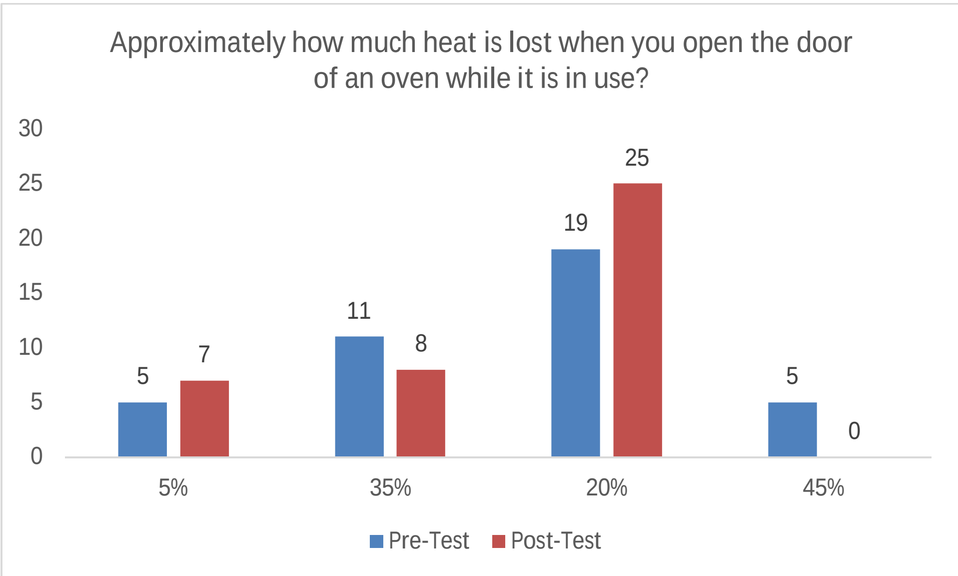


Figure 7.5: Heat Loss While Using Oven

7.2.6 Recommended Temperature for Water Heating in Dishwashers

The answer to this question is 115°F. Most of the participants (16) opted for 75°F in the pre-test experiment. However, 26 participants selected the right answer in the post-test experiment, which demonstrates a significant awareness of the correct answer.

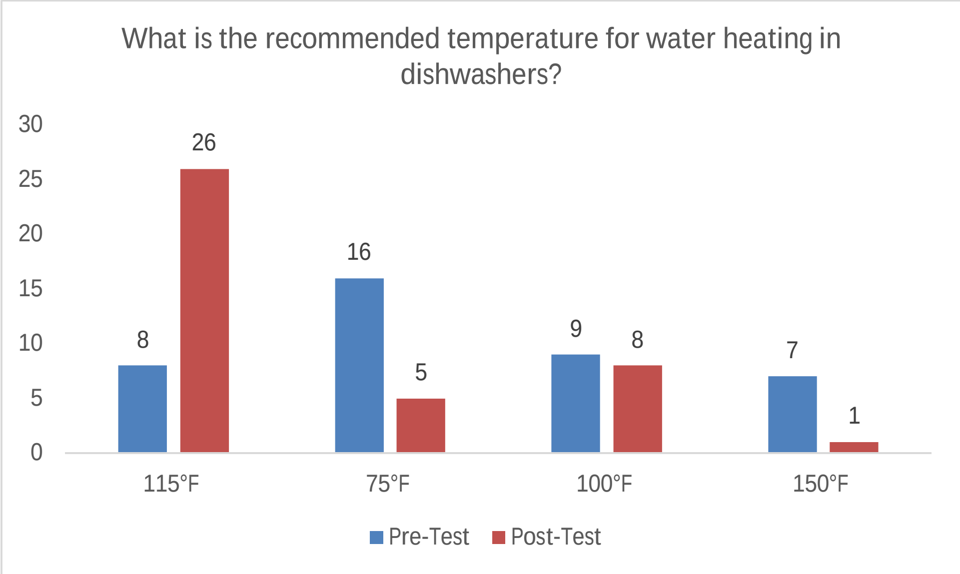


Figure 7.6: Recommended Temperature for Use in Dishwashers

7.2.7 Energy Consumption in Use of Printers

Most of the participants obtained the right answer both in the pre-test and post-test experiments, as shown in Figure 7.7. The figure increase from 25 to 38 participants in the post-test result.

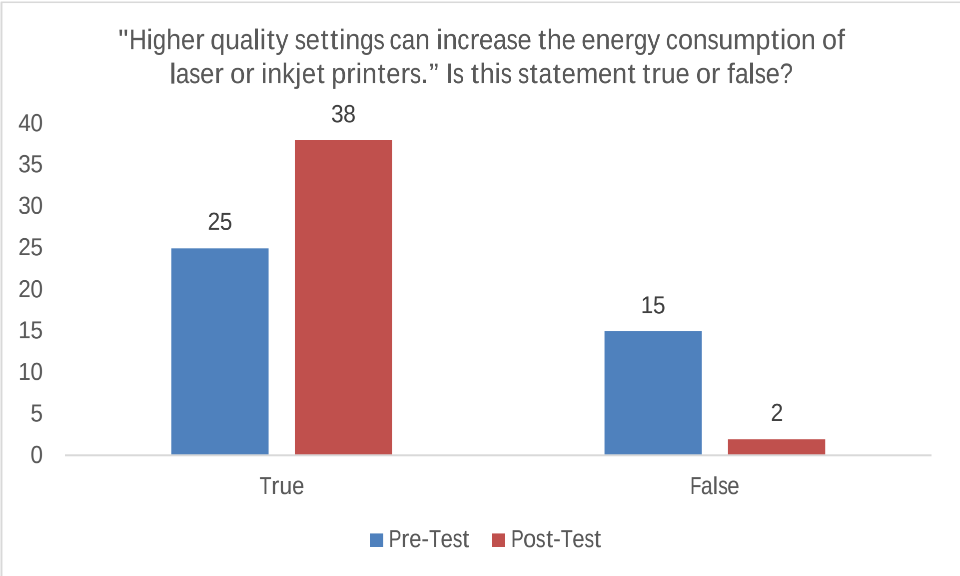


Figure 7.7: Energy Consumption in Printers

7.2.8 Replacement of Air Conditioner Filters

The participants were asked on how often air conditioner filters should be replaced. The answer is every 6 months. As seen in Figure 7.8 below, most of the participants (31) obtained the correct answer in the post-test result, which is almost twice the number of participants obtaining the right answer in the pre-test experiment.

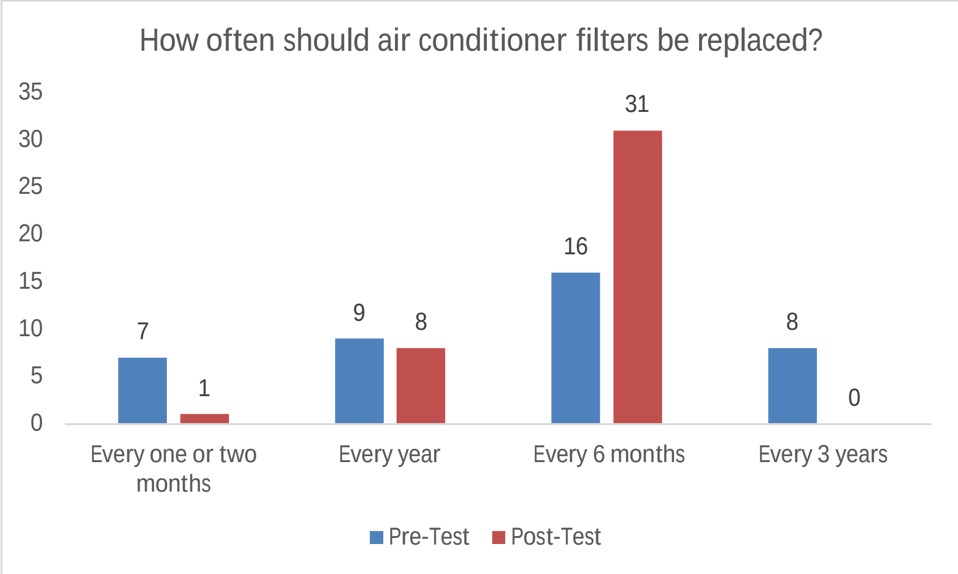


Figure 7.8: Replacement of Air Conditioners

7.2.9 Distance between Refrigerator and Wall

For this question, most of the participants obtained the correct answer in the pre-test and post-test experiments, 17 and 27 respectively as shown in Figure 7.9 below.

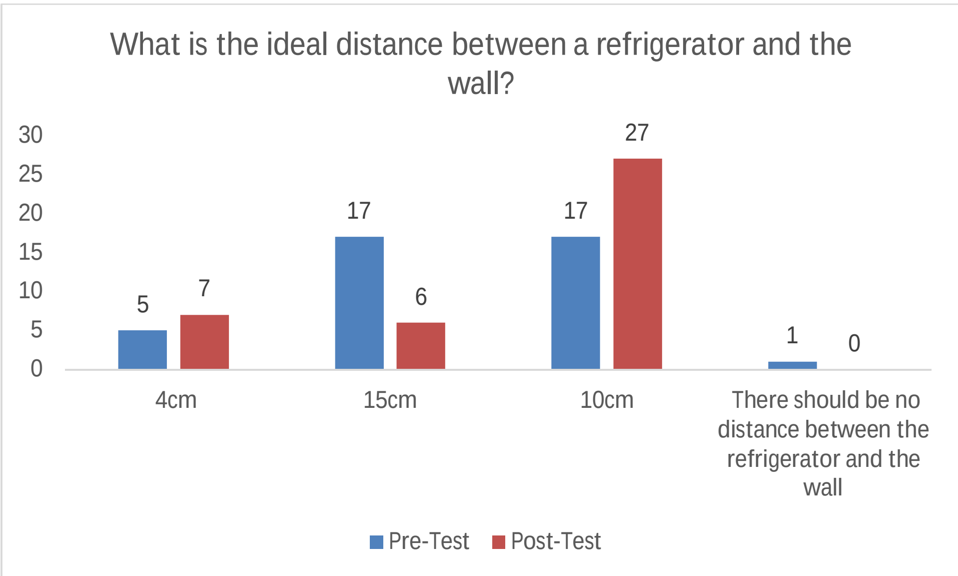


Figure 7.9: Ideal Distance between Refrigerator and Wall

7.2.10 The Most Energy-Saving Television Set

The participants were given four different statements on the most energy-saving type of television sets. In the pre-test experiment, there were many variations in the answers, as shown in Figure 7.10 below. However, in the post-test result, most of the participants (30) gave the correct answer, which was that plasma TVs consume less energy than LED or LCD TVs. This demonstrate that the application aided the participants to understand the correct answer.

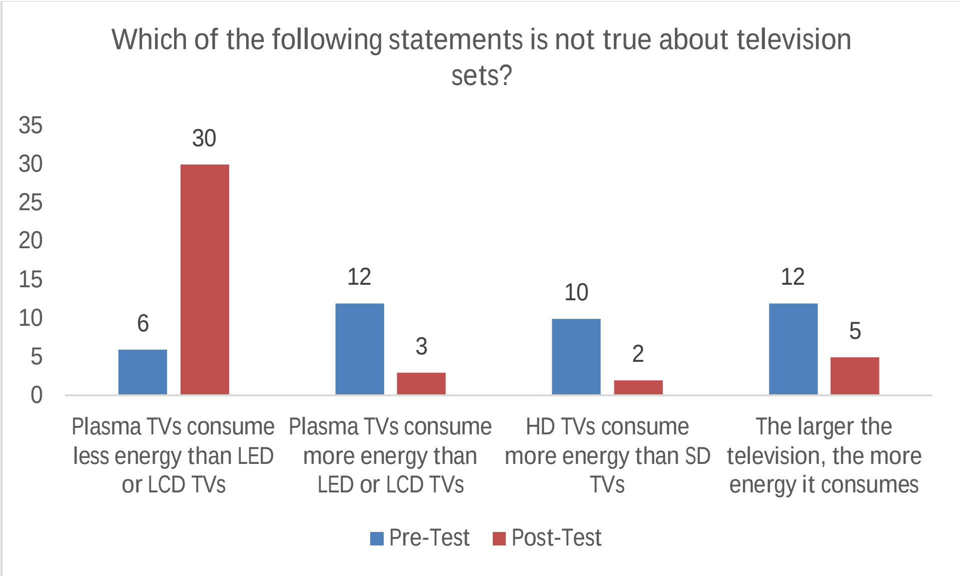


Figure 7.10: Energy-Saving Television Sets

7.2.11 Use of Microwave Ovens

For this question, there were many variations in the answers for the pre-test result. This is shown in Figure 7.11 below. The result indicates the participants were unsure of the correct answer. However, in the post-test result, most of the participants, 35 in total, obtained the correct answer and this means the application was helpful and met the initial objective of raising awareness on best practices.

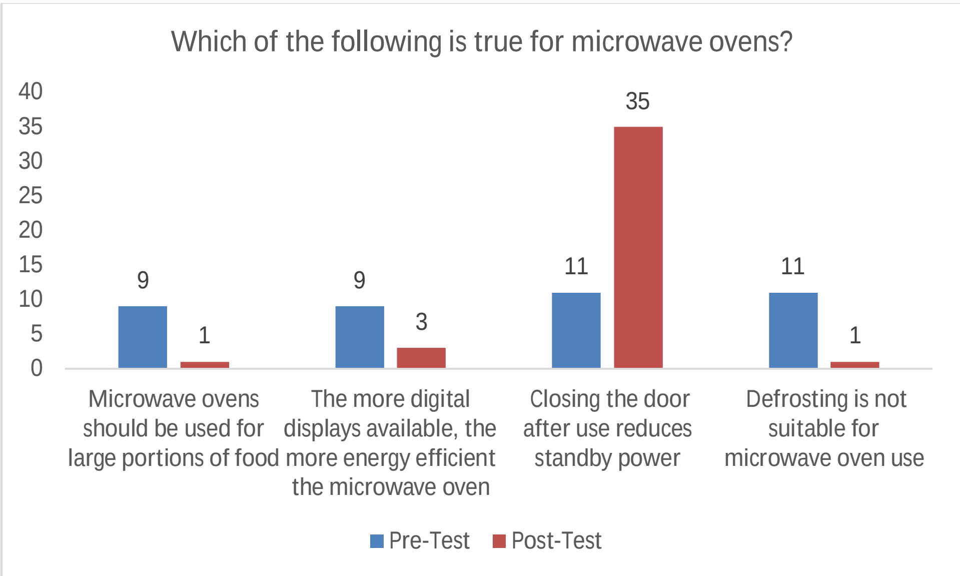


Figure 7.11: Best Practice when Using Microwave Ovens

7.2.12 Appropriate Brightness Level of Television Sets

For this question, most of the participants obtained the right answer in both the pre-test and post-test questionnaires. The number increased from 25 to 35 in the post-test results.

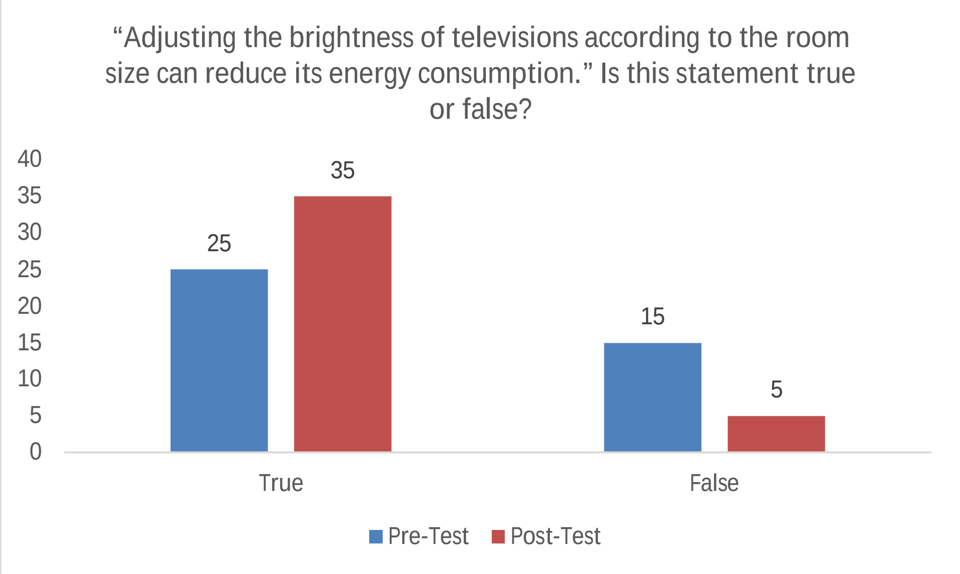


Figure 7.12: Television Brightness Adjustments to Reduce Energy Consumption

7.2.13 Best Practice While Using Washing Machines

The participants were asked on one of the best practices while using washing machines. The last statement as shown in Figure 7.13 was the correct answer. In the post-test result, 32 of the 40 participants obtained the correct answer, as compared to 17 from the pre-test result.

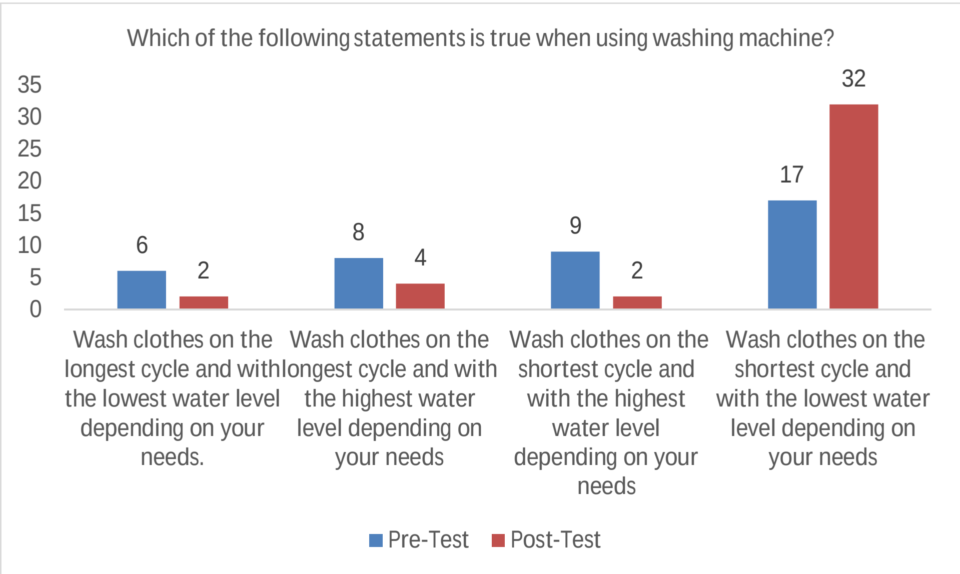


Figure 7.13: Best Practice on Using Washing Machine

7.2.14 Best Practice While Using Notebook Computers

For this question, 37 participants got the right answer in the post-test result as seen in Figure 7.14. Even if 16 participants obtained the correct answer in the pre-test result, after using the application there was a significant increase in the number of participants choosing the correct statement.

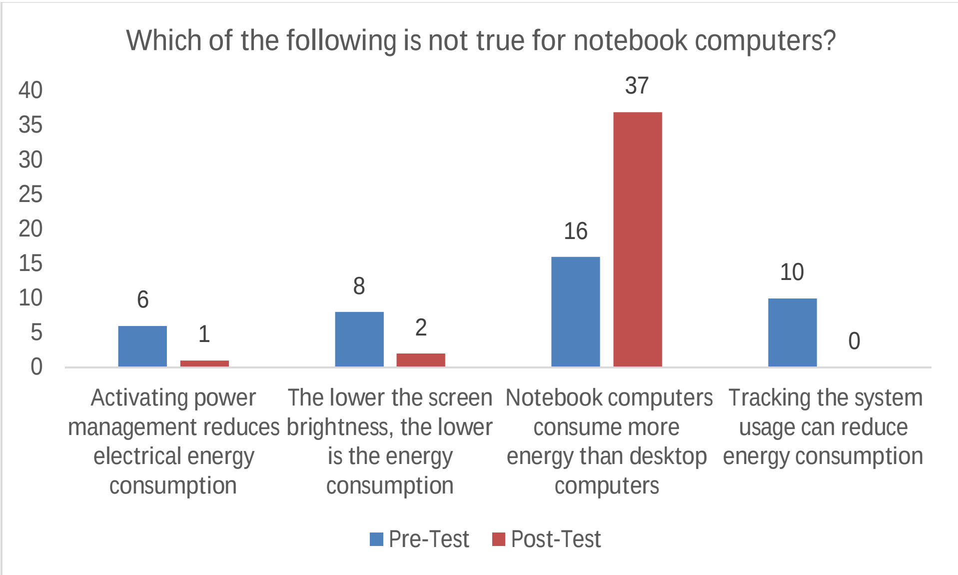


Figure 7.14: Best Practice on Using Notebook Computers

7.2.15 Suitable Type of Fans for Room Size

For this last questions, most of the participants chose the right answer in both the pre-test and post-rest experiments. There is a slight increase in the number of participants, from 27 to 35, who obtained the correct answer in the post-test activity.

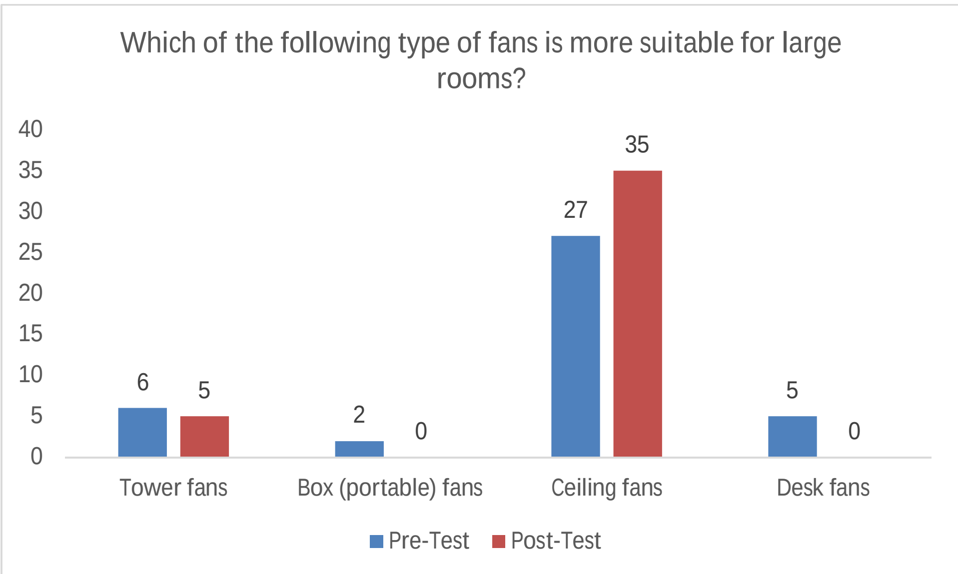


Figure 7.15: Most Suitable Type of Fan for Room Size

7.2.16 Critical Analysis

Overall, the results from the pre-test and post-test evaluations are positive. For all the 15 questions, the participants obtained the right answers in the post-test evaluation. This means that after using the application for a week, the participants were able to learn about the best practices on green energy consumption and this also answers the main research question which is that AR can be used a technological tool to enhance learning on green consumption practices. The results also indicate that for some of the questions, many of the participants already got the right answers in the pre-test evaluation. However, for the same questions, the number of participants obtaining the correct answers in the post-test evaluation increased, thereby indicating that the use of the prototype application has helped participants to learn more on the green practices regarding different appliances. A comparison was also made on the overall results from the pre-test and post-test evaluations. Averages of participants obtaining the right answers in both evaluations were calculated. The results show that in the pre-test evaluation, the average percentage of participants obtaining the correct answer was 40.8%. In the post-test evaluation result, that figure increased to 79.0%. This result shows that after using the application all the participants were able to learn more about their electrical and electronic appliances and the related green practices, and as such were able to answer all the questions correctly. Therefore, it can be concluded that the prototype application had enhanced the knowledge of the participants regarding green energy consumption practices, and was an effective learning tool.

7.3 Chapter Summary

In this chapter, a detailed analysis was given on the results of the user evaluation study. The results from the pre-test and post-test experiments were positive, since most of the participants showed an increase in awareness on the best practices while using electrical appliances. The responses were equally positive for the technology acceptance analysis.

Chapter 8– Conclusion and Future Works

In this chapter, a detailed summary of every phases of the research study is presented. The summary covers the initial part of the research study, starting with the literature review and taxonomy selection up till the design and development of the mobile application prototype and the evaluation and results analysis.

8.1 Research Summary

This research study investigates how AR technology would help in raising awareness on green consumption of electrical and electronic devices. Even if Mauritius is projecting itself as s sustainable island with high initiatives undertaken by the Government towards going green, the lack of knowledge is still considered as a major barrier to the implementation of environmentally sustainable actions. Mauritian households and businesses are growing more and more dependent on the growing number of electrical and electronic devices and as such, there is a growing need for them to be aware of the best practices to use such devices in an environmentally sustainable manner. In the literature review conducted, it was found out that in Mauritius, the per capita consumption of electricity increased by 2.0% from 1945 KWh in 2014 to 1984 KWh in 2015. This growth in electrical energy consumption inevitably has an impact on the natural environment. The various electrical and electronic appliances in use are responsible for the growing carbon dioxide emission. As such, the main focus of this study is to help individuals reduce their personal electrical energy consumption. A review of literature also indicated that the main barrier to a reduction in electronics consumption and a more energy efficient usage of the electrical appliances is the lack of knowledge and real time information. As such, among the different technological tools, augmented reality was selected as the most effective self-learning tool to be used to inform and engage electronic consumers on green consumption behaviours. So far, there are not many green mobile application which use the AR features to engage their users. This study sought to make maximum use of the features provided by the AR technology to help increase awareness of the green practices in using electrical appliances.

To achieve this objective, an augmented reality Android mobile application was developed. Before the application was designed, a taxonomy study was conducted on the green consumption of electronic devices. The taxonomy study helped in categorizing and providing an organised view of the different main types of electrical and electronic appliances. Several existing taxonomy of electronic devices were reviewed. One of the taxonomy analysed was selected and adopted for the study due to its comprehensive list of appliances. Afterwards the next phase to the application design phase. The functional and non-functional requirements of the mobile application to be developed were outlined in a tabular format. Among some of the functional requirements, the application should allow the users to scan their surroundings to detect the electrical appliances and view the digital overlay on the camera screen of their devices. Users must be able to freely activate and de-activate any devices in use and the system should automatically display the energy consumption and duration during which any particular appliance was in use. The different screen designs were also presented using Balsamiq Mockups software. Afterwards, the use case diagram and scenarios were discussed, and these were followed by the class and sequence diagrams.

After the application design chapter, the mobile application was then implemented and tested. The application was developed in Unity 5 and Vuforia plug-in. Vuforia was selected because the detection of different image and small 3D object targets. However, during the development stage it was noticed that it was not possible to detect large 3D objects like refrigerators or washing machines with Vuforia SDK. Since there were no other commercially available SDKS to detect large 3D objects, the application thus made use of image targets which represented different electrical appliances. One feature of the application allowed the users to make use the camera from their mobile devices to scan those image targets. On scanning the images, the users have the options to view their energy consumption when the appliances were in use, and also to view different tips on how to best use the particular electrical appliance so as to reduce the energy consumption. Users of the application were also able to assess their energy efficiency level by answering a series of questions using an energy efficiency assessment mechanism. The AR application was designed in such a way to evaluation the knowledge gains of users on green consumption of electrical appliances through the AR technology.

After developing the application, a user evaluation was conducted among forty participants to investigate the hypothesis. This evaluation lasted for one week, with students and staffs of Middlesex University Mauritius Branch Campus. A pre-test and post-test design approach was used to assess the knowledge gains of the participants, and they were also given the AR mobile application to use. After the user evaluation was done, the results were analysed. There was a significant difference between the pre-test and post-test results. Most of the participants showed a better awareness of the green consumption practices after using the AR application. The results from the technology acceptance questionnaire were equally positive, with most of the participants showed their interest and intention in using the application, with 52.5% of the participants regarding the application to be a useful learning tool. The participants found the application enjoyable to use and user-friendly. Furthermore, the results from the technology acceptance model also indicated that the participants expressed their interest in using such an AR technology as a learning tool for green energy consumption of electrical appliances. 16 out of 21 participants agreed that they would use the application to enhance their knowledge on green consumption of electronic devices given access to it.

8.2 Research Study Limitations

There were a few challenges in this research study, both during the development of the AR application and the user evaluation experiment. Initially, the AR application was designed to automatically detect 3D objects, like refrigerators, washing machines or any other electrical appliances. However, since there were no commercially available AR SDKS to accurately scan and detect large 3D objects, it was not possible to achieve this initial goal. An alternative solution had to be implemented, in the form of marker-based AR detection. Images representing the electrical appliances were used as markers to enable the detection of the appliances. Another limitation in the user evaluation was the fact that the participants had no previous knowledge or experience in using any AR technology before. As such, it was challenging to properly investigate the ease of use of the technology, and many participants had to be quickly briefed on how to scan the images so as to properly use the application.

8.3 Future Works

With regard to future works, an extended research could be done to investigate the use of marker-less feature to detect large AR objects. Nowadays, considerable research is being done in the field of AR and many new technologies are currently being developed to cater to the present limitations of existing AR SDKs. As such, this application could be further developed to detect large 3D objects effortlessly. Furthermore, a limited number of electrical appliances were used in the study to assess the knowledge of participants. This figure could be increased to provide more in-depth analysis of the knowledge of electrical appliance consumers. This research study was conducted on a small scale at Middlesex University Mauritius Branch Campus. As such, it could be expanded to other local universities, and to a larger scale at the industrial level. The application could be tested and used by employers to help their employees to measure and track their energy consumption at offices. The application could also be further refined and promoted by making it commercially available to the public.

List of references

California Energy Commission, 2008. *Energy Use of Household Electronics: Taming the Wild Growth,* California: State of California Energy Commission.

Agency Federal Emergency Management, 2015. *Technological Development and Dependency: Long-term Trends and Drivers and Their Implications for Emergency Management,* Washington: Federal Emergency Management Agency.

Alfredsson, 2004. ''Green'' consumption—no solution for climate change. *Energy,* Volume 29, p. 513–524.

Alfredsson, E., 2002. *Green consumption energy use and carbon dioxide emission,* Solfjädern, Umeå: Eva Alfredsson.

Almeida, A. d., Fonseca, P., Schlomann, B. & Feilberg, N., 2010. *Characterization of the Household Electricity Consumption in the EU, Potential Energy Savings and Specific Policy Recommendations.* s.l.:s.n.

Antonacci, D. et al., 2008. *The Power of Virtual Worlds in Education,* United States: The ANGEL Learning Isle Steering Committee .

Azuma, R., 1995. A survey of augmented reality. *Presence,* 6(4), p. 355–385.

Azuma, R., 1997. A survey of augmented reality. *Presence,* 6(4), pp. 355-385.

Baldé, C. P., Wang, F., Kuehr, R. & Huisman, J., 2015. *The Global E-Waste Monitor 2014: Quantities, flows and resources,* Bonn, Germany: United Nations University.

Bekaroo, G. & Bokhoree, C., 2011. *Towards Emerging Green Information and Communication Technologies: A Review.* s.l., s.n., pp. 428-433.

Bertoldi, P. & Atanasiu, B., 2007. *Electricity Consumption and Efficiency Trends in the Enlarged European Union - Status report 2006,* Italy: European Communities.

Bretagne Commerce International , 2015. *Energy management: Energiency launches field's 1st Augmented Reality app.* [Online]
Available at: http://www.bretagnecommerceinternational.com/en/2015/05/07/energy-management-energiency-launches-fields-1st-augmented-reality-app/
[Accessed 10 November 2015].

Brown, R. E., Rittelman, W., Parker, D. & Homan, G., 2007. *Appliances, Lighting, Electronics, and Miscellaneous Equipment Electricity Use in New Homes.,* California: Use in New Homes. Lawrence Berkeley National Laboratory.

CarbonTrust, 2005. *Office equipment: Introducing energy saving opportunities for business,* United Kingdom: Carbon Trust Company.

Central Electricity Board, 2013. *Integrated Electricity Plan 2013-2022,* Ebene: Central Electricity Board.

Charter, M., Peattie, K., Ottman, J. & Polonsky, J. M., 2002. *Marketing and sustainability,* UK: Centre for Business Relationships, Accountability, Sustainability and Society.

Cheng, J. W., Gail, K. & Joseph, S. L., 2006. *Electric-load intelligence (E-LI): concept and applications..* s.l., IEEE Region 10 Conference.

Chesney, T., 2006. An Acceptance Model for Useful and Fun Information Systems. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments,* 2(2), pp. 225-235.

Chetty, M., Tran, D. & Grinter, R. E., 2008. *Getting to Green: Understanding Resource Consumption in the Home.* Seoul, Korea, UbiComp.

Coimbra, T., Cardoso, T. & Mateus, A., 2015. Augmented Reality: an Enhancer for Higher Education Students in Math's learning?. *Procedia Computer Science,* Volume 67, p. 332 – 339 .

Coleman, M., Brown, N., Wright, A. & Firth, S. K., 2012. Information, communication and entertainment appliance use – insights from a UK household study. *Energy and Buildings,* Volume 54, pp. 61-72.

Crosbie, T., 2008. Household energy consumption and consumer electronics: The case of television. *Energy Policy,* 36(6), pp. 2191-2199.

Darby, S., 2000. *Making it obvious: designing feedback into energy consumption.* Italy, Italian Association of Energy Economists/ EC-SAVE programme.

Dede, C., 2009. Immersive interfaces for engagement and learning. *Science,* 323(5910), pp. 66-69.

Department of Environment Food and Rural Affairs, 2002. *Delivering Emission Reductions,* United Kingdom: DEFRA.

Dookhitram, K. et al., 2012. *Green Computing: An Awareness Survey among University of Technology, Mauritius Students.* Mauritius, Conference Proceeding of International Conference on Higher Education and Economic Development.

Duke Energy Progress, 2015. *100 Ways to Save Energy at Home.* [Online]
Available at: https://www.progress-energy.com/carolinas/home/save-energy-money/energy-saving-tips-calculators/100-tips.page?
[Accessed 18 November 2015].

Energy Australia, 2015. *Energy Saving Tips.* [Online]
Available at: http://www.energyaustralia.com.au/residential/energy-saving-safety/energy-saving-tips#/The%20Bathroom
[Accessed 18 November 2015].

Energy Saving Trust, 2015. *Home appliances.* [Online]
Available at: http://www.energysavingtrust.org.uk/domestic/home-appliances
[Accessed 10 November 2015].

Enervee, 2015. *What Impacts the Efficiency of Projectors?.* [Online]
Available at: https://enervee.com/energy-efficiency-education-center/products/projectors-what-

impacts-efficiency/
[Accessed 18 November 2015].

European Commision, 2007. *Status Report 2006,* Italy: European Communities.

European Commission, 2013. *A Consumer's Guide to finding the right Energy Efficient Vacuum Cleaners,* s.l.: European Commission.

European Environment Agency, 2015. *Final energy consumption by sector and fuel.* [Online]
Available at: http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment
[Accessed 10 November 2015].

Eurostat, 2016. *Electricity production, consumption and market overview.* [Online]
Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview
[Accessed 6 August 2016].

Exxon Mobil Corporation, 2015. *Residential and commercial growth.* [Online]
Available at: http://corporate.exxonmobil.com/en/energy/energy-outlook/evolving-consumer-demand/residential-and-commercial-growth
[Accessed 9 November 2015].

Fanara, A., Clark, R., Duff, R. & Polad, M., 2015. *How Small Devices are Having a Big Impact on U.S. Utility Bills,* United States: Energystar.

Fernandes, B. & Miranda, J. C., 2003. *Learning how computer works with augmented reality.* s.l., s.n.

Future Market Insights, 2015. *Global Consumer Electronics Market: Demand from Consumers in Emerging Countries Key for Growth.* [Online]
Available at: http://www.futuremarketinsights.com/articles/consumer-electronics-market
[Accessed 4 October 2015].

Gallachóir, B. P. O., Keane, M., Morrissey, E. & O'Donnell, J., 2007. Using indicators to profile energy consumption and to inform energy policy in a university—A case study in Ireland. *Energy and Buildings ,* Volume 39, pp. 913-922.

Gilg, A., Barr, S. & Ford, N., 2005. Green consumption or sustainable lifestyles? Identifying the sustainable consumer. *Futures,* Volume 37, p. 481–504.

Goodyear, P., 2005. Educational design and networked learning: Patterns, pattern languages and design practice. *Australasian Journal of Educational Technology,* 21(1), pp. 82-101.

Google , 2015. *Museum of London: Streetmuseum.* [Online]
Available at: https://play.google.com/store/apps/details?id=com.streetmuseum&hl=en
[Accessed 22 October 2015].

Google, 2015. *Dia Saves Energy.* [Online]
Available at:

https://play.google.com/store/apps/details?id=com.wearespectre.diasavesenergy&hl=en
[Accessed 15 November 2015].

Gov.UK, 2015. *2010 to 2015 government policy: energy demand reduction in industry, business and the public sector.* [Online]
Available at: https://www.gov.uk/government/publications/2010-to-2015-government-policy-energy-demand-reduction-in-industry-business-and-the-public-sector/2010-to-2015-government-policy-energy-demand-reduction-in-industry-business-and-the-public-sector#contents
[Accessed 10 November 2015].

Government of the Netherlands, 2015. *Saving Energy.* [Online]
Available at: https://www.government.nl/topics/energy-policy/contents/saving-energy
[Accessed 10 November 2015].

Gurauskienė, I. & Varžinskas, V., 2006. Eco-design Methodology for Electrical and Electronic Equipment Industry. *Environmental research, engineering and management,* 3(37), pp. 43-51.

Hearst Communications, Inc, 2015. *5 Ways to Save Money on Air Conditioning.* [Online]
Available at: http://www.goodhousekeeping.com/life/money/advice/a25798/save-money-air-conditioning/
[Accessed 18 November 2015].

Hertwich, E. G., 2005. Life Cycle Approaches to Sustainable Consumption: A Critical Review. *Environmental Science and Technology,* 29(13), pp. 4673-4684.

Hinge, A., Bertoldi, P. & Waide, P., 2004. *Comparing Commercial Building Energy Use Around the World.* s.l., ECEEE.

Horowitz, N., 2011. *Overview of World-Wide Energy Consumption of Consumer Electronics and Energy Savings Opportunities* , s.l.: Natural Resources Defense Council.

Institute for European Environmental Policy, 2009. *A Report on the Implementation of Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE)* , s.l.: Institute for European Environmental Policy.

International Energy Agency , 2014. *More Data, Less Energy: Making Network Standby More Efficient in Billions of Connected Devices,* Paris: International Energy Agency .

International Energy Agency, 2012. *Electricity Information,* Paris: International Energy Agency.

Japan Electronic and Information Technology Industries Association, 2016. *2016 Production Forecast for the Global Electronics and Information Technology Industries,* Japan: JEITA.

Japan Electronics and Information Technology Industries Association, 2014. *2015 Production Forecasts for the Global Electronics and Information Technology Industries* , Japan: Japan Electronics and Information Technology Industries Association.

Jeong, M.-G., Suh, H.-W. & Morrison, J. R., 2010. A framework for stepwise life cycle assessment during product design with case-based reasoning.. *2010 IEEE International Conference on Automation Science and Engineering,* pp. 118-123.

Johnson, L. et al., 2011. *The 2011 Horizon Report,* Austin, Texas: The New Media Consortium.

Kalz, M., Börner, D., Ternier, S. & Specht, M., 2015. *Mindergie: A pervasive learning game for pro-environmental behaviour at the workplace,* Netherlands: Open University of the Netherlands.

King, W. R. & He, J., 2006. A meta-analysis of the technology acceptance model. *Information and Management,* 43(6), p. 740–755.

Klopfer, E. & Sheldon, J., 2010. Augmenting your own reality: Student authoring of science-based augmented reality games.. *New Directions for Youth Development,* Volume 128, p. 85–94.

Kose, U., Koc, D. & Yucesoy, S. A., 2013. An Augmented Reality Based Mobile Software to Support Learning Experiences in Computer Science Courses. *Procedia Computer Science,* Volume 25, p. 370 – 374 .

Lam, H. Y., Fung, G. S. K. & Lee, W. K., 2007. A Novel Method to Construct Taxonomy of Electrical Appliances Based on Load Signatures. *Ieee Transactions On Consumer Electronics,* 53(2), pp. 653-660.

Lewis, H. & Gertsakis, J., 2001. *Design & Environment, A Global Guide to Designing Greener Goods.* 1st ed. s.l.:Greenleaf Publishing.

Lorenzoni, I., Nicholson-Cole, S. & Whitmarsh, L., 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change,* Volume 17, p. 445–459.

Manyika, J. et al., 2013. *Disruptive technologies: Advances that will transform life, business, and the global economy,* San Francisco: McKinsey & Company.

Martin-Gutierrez, J., Guinters, E. & Perez-Lopez, D., 2012. Improving strategy of self-learning in engineering: laboratories with augmented reality. *Procedia - Social and Behavioral Sciences ,* Volume 51, p. 832 – 839 .

Martín-Gutiérrez, J. et al., 2010. Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics,* 34(1), p. 77–91.

Mathews, J. M., 2010. Using a studio-based pedagogy to engage students in the design of mobile-based media.. *English Teaching: Practice and Critique,* 9(1), pp. 87-102.

Mattern, F., Staake, T. & Weiss, M., 2010. *ICT for green: how computers can help us to conserve energy.* s.l., s.n., pp. 1-10.

Maurice Ile Durable, 2015. *Energy and Climate.* [Online]
Available at: http://mid.govmu.org/portal/sites/mid/WG1Energy.htm
[Accessed 10 November 2015].

Mccalley, L. T. & Midden, C. J. H., 2002. Energy conservation through product-integrated feedback: the roles of goal-setting and social orientation.. *Journal of Economic Psychology,* Volume 23, pp. 589-603.

Michaelides, E. E., 2012. *Environmental and Ecological Effects of Energy Production and Consumption,* Berlin: Springer-Verlag.

Milgram, P. & Kishino, A. F., 1994. Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems,* E77-D(12), pp. 1321-1329.

Murugesan, S., 2008. Harnessing green IT: Principles and practices. *IT professional,* 10(1), pp. 24-33.

National Investiment Promotional Agency, 2014. *Sector Analysis: Renewable Energy,* Port Louis: Board of Investiment.

Natural Resources Defense Council, 2015. *How to Reduce Your Energy Consumption.* [Online]
Available at: http://www.nrdc.org/air/energy/genergy.asp
[Accessed 10 November 2015].

Natural Resources Defense Council, 2015. *How to Reduce Your Energy Consumption.* [Online]
Available at: http://www.nrdc.org/air/energy/genergy.asp
[Accessed 18 November 2015].

Nielsen Norman Group, 2016. *How Many Test Users in a Usability Study?.* [Online]
Available at: https://www.nngroup.com/articles/how-many-test-users/
[Accessed 25 June 2016].

Nnorom, I. C. & Osibanjo, O., 2008. Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. *Resources, conservation and recycling,* 52(6), pp. 843-858.

Nordman, B. & Sanchez, M. C., 2006. *Electronics Come of Age: A Taxonomy for Miscellaneous and Low Power Products,* California: Lawrence Berkeley National Laboratory.

Nordman, B. & Sanchez, M. C., 2006. *Electronics Come of Age: A Taxonomy for Miscellaneous and Low Power Products,* California: Lawrence Berkeley National Laboratory.

O'Neill, B. C. & Oppenheimer, M., 2002. Climate change: dangerous climate impacts and the Kyoto Protocol. *Science,* 296(5575), pp. 1971-1972.

Pan, S., Liu, B., Zhang, L. & Zhang, P., 2012. Demo Abstract: iCEnergy: Augmented Reality Display for Intuitive Energy Monitoring. *SenSys,* Volume 12, pp. 6-9.

Pan, Z. et al., 2006. Virtual reality and mixed reality for virtual learning environments. *Computers & Graphics,* Volume 30, pp. 20-28.

Peattie, K., 2010. Green Consumption: Behaviour and Norm. *Annual Review of Environment and Resources,* Volume 135, pp. 195-228.

Peattie, K. & Moira, R., 1992. Responding to the green movement. *Industrial Marketing Management,* 21(2), pp. 103-110.

Poortinga, W., Pidgeon, N. & Lorenzoni, I., 2006. *Public Perceptions of Nuclear Power, Climate Change and Energy Options in Britain: ummary Findings of a Survey Conducted during October and November 2005,* Norwich: University of East Anglia.

PowerHouse, 2015. *101 ways to save energy.* [Online]
Available at: http://www.powerhousetv.com/Energy-EfficientLiving/Energy-savingsTips/027471
[Accessed 18 November 2015].

Ramgolam, Y. K. et al., 2014. *Energy Profiles and Performance of Common Electrical Domestic Appliances.* Cavtat, Energy Conference IEEE International.

Rosenbaum, E., Klopfer, E. & Perry, J., 2007. On location learning: Authentic applied science with networked augmented realities.. *Journal of Science Education and Technology,* 16(1), pp. 31-45.

Roth, K. W., Larocque, G. R. & Kleinman, J., 2004. *Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings Volume 2: Energy Savings Potential,* Springfield: National Technical Information Service, US Department of Commerce.

Sapountz, D. & Oungrinis, K.-A., 2015. *Augmenting Urban Green Awareness.* Chania, Greece, Technical University of Crete.

Sayed, N. A. M. E., Zayed, H. H. & Sharawy, M. I., 2011. ARSC: Augmented reality student card-An augmented reality solution for the education field.. *Computers & Education,* 56(4), pp. 1045-1061.

Scipioni, A., Mastrobuono, M., Mazzi, A. & Manzardo, A., 2010. Voluntary GHG management using a life cycle approach. A case study. *Journal of Cleaner Production,* Volume 18, p. 299–306.

Sepúlveda, A. et al., 2010. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. *Environmental Impact Assessment Review,* Volume 30, p. 28–41.

Shelton, B. E. & Hedley, N. R., 2002. *Using augmented reality for teaching earth-sun relationships to undergraduate geography students.* s.l., IEEE, p. 8.

Shina, S., 2008. *Green electronics design and manufacturing.* s.l.:McGraw-Hill, Inc..

Silberglitt, R., Antón, P. S., Howell, D. R. & Wong, A., 2006. *The Global Technology Revolution 2020: Executive Summary,* California: RAND Corporation.

Spectre, 2015. *Dia Saves Energy AR.* [Online]
Available at: http://www.wearespectre.com/work/dia-saves-energy-ar
[Accessed 5 November 2015].

Statista, 2015. *Number of mobile phone users worldwide from 2013 to 2019 (in billions).* [Online]
Available at: http://www.statista.com/statistics/274774/forecast-of-mobile-phone-users-worldwide/
[Accessed 12 November 2015].

Statistic Mauritius, 2015. *Household Budget Survey 2012,* Port Louis: Statistic Mauritius.

Statistics Mauritius, 2016. *Energy and Water.* [Online]
Available at: http://statsmauritius.govmu.org/English/StatsbySubj/Pages/Energy-and-Water.aspx
[Accessed 6 August 2016].

Statistics Mauritius, 2016. *ICT Statistics Year 2015.* [Online]
Available at: http://statsmauritius.govmu.org/English/Publications/Pages/ICT-Statistics-Year-2015.aspx
[Accessed 16 August 2016].

Sustainable Energy Authority of Ireland , 2013. *Your Guide to Electricity in the Home,* Ireland: SEAI.

The British standard Institution, 2011. *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services,* UK: BSI.

The State Electronics Challenge, 2015. *Saving Energy with Office Equipment,* Brattleboro,: The State Electronics Challenge.

U.S Energy Information Administration, 2011. *Share of energy used by appliances and consumer electronics increases in U.S. homes.* [Online]
Available at: http://www.eia.gov/consumption/residential/reports/2009/electronics.cfm
[Accessed 11 November 2015].

U.S. Department of Energy, 2008. *Energy Efficiency Trends in Residential and Commercial Buildings,* The United States of America: U.S. Department of Energy.

U.S. Department of Energy, 2015. *Fans for cooling.* [Online]
Available at: http://energy.gov/energysaver/fans-cooling
[Accessed 18 November 2015].

Uddin, M. & Rahman, A. A., 2012. Energy efficiency and low carbon enabler green IT framework for data centers considering green metrics. *Renewable and Sustainable Energy Reviews,* 16(6), pp. 4078-4094.

UK Department of Energy and Climate Change, 2012. *Electricity Demand Reduction: Consultation on options to encourage permanent reductions in electricity use,* London: The Stationery Office Limited.

UNEP, 2001. *Consumption Opportunities: Strategies for Change,* Paris: UNEP.

UNEP, 2015. *Life Cycle Assessment.* [Online]
Available at:
http://www.unep.org/resourceefficiency/Consumption/StandardsandLabels/MeasuringSustainability/LifeCycleAssessment/tabid/101348/Default.aspx
[Accessed 30 October 2015].

United Nations Environment Programme, 2015. *Anticipating the Environmental Effects of Technology.* [Online]

Available at: http://www.unep.or.jp/ietc/Publications/Integrative/EnTA/AEET/6.asp
[Accessed 11 November 2015].

United Nations Environment Programme, 2016. *Why Buildings.* [Online]
Available at: http://www.unep.org/sbci/AboutSBCI/Background.asp
[Accessed 6 August 2016].

United Nations Environment Programme, 2016. *Why Buildings.* [Online]
Available at: http://www.unep.org/sbci/AboutSBCI/Background.asp
[Accessed 10 8 2016].

Unity Technologies, 2016. *Unity.* [Online]
Available at: https://unity3d.com/unity
[Accessed 18 May 2016].

UNU, 2007. *Review of Directive 2002/96 on Waste Electrical and Electronic Equipment WEEE,* Bonn: Final Report to European Commission.

uSwitch, 2015. *Energy-efficient cooking.* [Online]
Available at: http://www.uswitch.com/energy-saving/guides/energy-efficient-cooking/
[Accessed 18 November 2015].

Vandenbergh, M. P., Dietz, T. & Stern, P. C., 2011. Time to try carbon labelling. *Nature Climate Change,,* Volume 1, pp. 4-6.

Wabwoba, F., Wanyembi, G. W. & Omuterema, S., 2012. Barriers to Implementation of Green ICT in Kenya. *International Journal of Science and Technology,* 2(12).

Wagner, D., Pintaric, T., Ledermann, F. & Schmalstieg, D., 2005. *Towards massively multi-user augmented reality on handheld devices.* s.l.:Springer.

Wake Forest University, 2009. *Printing: How to Go Green and Save Green,* Winston-Salem: Wake Forest University.

Wang, J. & Zhou, Z., 2014. *Energy Efficient Light Control System,* s.l.: University of Gavle.

Watson, R. T., Zinyowera, M. C. & Moss, R. H., 1996. *Climate Change 1995 impacts, adaptations and mitigation of climate change: Scientific-technical analysis,* s.l.: Cambridge University Press.

Widmer, R. et al., 2005. Global perspectives on e-waste. *Environmental Impact Assessment Review,* 25(5), p. 436–458.

Woods, G. & Newborough, M., 2003. Dynamic energy consumption indicators for domestic appliances: environment, behaviour and design.. *Energy and Buildings,* 35(8), pp. 821-841.

World Energy Council, 2015. *Energy Efficiency Indicators.* [Online]
Available at: https://www.wec-indicators.enerdata.eu/household-electricity-use.html#/electricity-use-per-capita.html
[Accessed 6 November 2015].

Wu, H.-K., Lee, S. W.-Y. & Chang, H.-Y., 2013. Current status, opportunities and challenges of augmented reality in education. *Computers & Education,* Volume 62, p. 41–49.

Zaman, H. B. et al., 2009. *Visual Informatics: Bridging Research and Practice.* Kuala Lumpur, First International Visual Informatics Conference.

Appendix A

Pre-test Multiple-Choice Questionnaire

The following questionnaire was used in the pre-test experiment for the user evaluation activity:

Towards Green Consumption of Electronic Devices: *Using Augmented Reality to Improve Awareness*

This research study involves the development of an Augmented Reality application to help individuals track and reduce their energy consumption from electrical and electronic appliances. The application aims at increasing awareness on green utilization of both household and office appliances.

This project is being conducted by Middlesex University (Mauritius Branch Campus) in collaboration with the University of Mauritius, and is being funded by Mauritius Research Council.

OATH OF CONFIDENTIALITY

This is to certify that any information (written, verbal or other form) obtained during the performance of this survey will remain confidential. This includes all the information about the participants and any other confidential information being asked in this survey.

We understand that any unauthorized release or carelessness in the handling of this survey questionnaire is considered a breach of the duty to maintain confidentiality. Any breach of duty in maintaining confidentiality is liable to any legal action arising from such breach.

PLEASE NOTE

- You are not required to identify yourself and your responses shall not reveal your identification.
- Feel free to seek any clarification and ask any question(s) regarding the research project from the investigator.
- All responses will be treated in strict confidentiality and will be used solely for academic research purposes.
- Your individual response is highly valued, thus it would be appreciated if you do not confer with others while filling in this survey questionnaire.
- Please note there are no right or wrong answers for the survey questions.
- Completing this questionnaire should take approximately 10 minutes.

Kindly respond to the questions below by circling the required alphabet and please answer all questions.

1. Which of the following definitions is correct for the term kilowatt-hour?
   A. Equal to 1,000 watt-hours
   B. Unit used by utility company
   C. Measure electrical energy consumed in one hour
   D. All of the above

2. Which of the following is true about electric ovens?
   A. Use glass or ceramic dishes in the oven
   B. Food should be cut into smaller pieces to speed up cooking process
   C. Fan assist cooking option saves more energy
   D. All of the above

3. Approximately how many hours of electricity is consumed when you leave your television on standby mode at night?
   A. 2 hours viewing time

B. 4 hours viewing time
C. 8 hours viewing time
D. 10 hours viewing time

4. Which of the following types of bulbs is more energy saving?
   A. Light Emitting Diodes (LEDs)
   B. Incandescent bulbs
   C. Compact Fluorescent Lamps (CFLs)
   D. Halogen Incandescent bulbs

5. Approximately how much heat is lost when you open the door of an oven while it is in use?
   A. 5%
   B. 35%
   C. 20%
   D. 45%

6. What is the recommended temperature for water heating in dishwashers?
   A. 115°F
   B. 75°F
   C. 100°F
   D. 150°F

7. Higher quality settings can increase the energy consumption of laser or inkjet printers.” Is this statement true or false?
   A. True
   B. False

8. How often should air conditioner filters be replaced?
   A. Every one or two months
   B. Everything year
   C. Every 6 months
   D. Every 3 years

9. What is the ideal distance between a refrigerator and the wall?
   A. 4cm
   B. 15cm
   C. 10cm
   D. There should be no distance between the refrigerator and the wall

10. Which of the following statements is not true about television sets?
    A. Plasma TVs consume less energy than LED or LCD TVs
    B. Plasma TVs consume more energy than LED or LCD TVs
    C. HD TVs consume more energy than SD TVs
    D. The larger the television, the more energy it consumes

11. Which of the following is true for microwave ovens?
    A. Microwave ovens should be used for large portions of food
    B. The more digital displays available, the more energy efficient the microwave oven
    C. Closing the door after use reduces standby power
    D. Defrosting is not suitable for microwave oven use

12. “Adjusting the brightness of televisions according to the room size can reduce its energy consumption.” Is this statement true or false?
    A. True
    B. False

13. Which of the following statements is true when using washing machine?
    A. Wash clothes on the longest cycle and with the lowest water level depending on your needs.
    B. Wash clothes on the longest cycle and with the highest water level depending on your needs
    C. Wash clothes on the shortest cycle and with the highest water level depending on your needs
    D. Wash clothes on the shortest cycle and with the lowest water level depending on your needs
14. Which of the following is not true for notebook computers?
    A. Activating power management reduces electrical energy consumption
    B. The lower the screen brightness, the lower is the energy consumption
    C. Notebook computers consume more energy than desktop computers
    D. Tracking the system usage can reduce energy consumption

15. Which of the following type of fans is more suitable for large rooms?
    A. Tower fans
    B. Box (portable) fans
    C. Ceiling fans
    D. Desk fans

Appendix B

Post-test Multiple-Choice Questionnaire

The following questionnaire was used in the post-test experiment for the user evaluation activity:

Towards Green Consumption of Electronic Devices: *Using Augmented Reality to Improve Awareness*

This research study involves the development of an Augmented Reality application to help individuals track and reduce their energy consumption from electrical and electronic appliances. The application aims at increasing awareness on green utilization of both household and office appliances.

This project is being conducted by Middlesex University (Mauritius Branch Campus) in collaboration with the University of Mauritius, and is being funded by Mauritius Research Council.

OATH OF CONFIDENTIALITY

This is to certify that any information (written, verbal or other form) obtained during the performance of this survey will remain confidential. This includes all the information about the participants and any other confidential information being asked in this survey.

We understand that any unauthorized release or carelessness in the handling of this survey questionnaire is considered a breach of the duty to maintain confidentiality. Any breach of duty in maintaining confidentiality is liable to any legal action arising from such breach.

PLEASE NOTE

- You are not required to identify yourself and your responses shall not reveal your identification.
- Feel free to seek any clarification and ask any question(s) regarding the research project from the investigator.
- All responses will be treated in strict confidentiality and will be used solely for academic research purposes.
- Your individual response is highly valued, thus it would be appreciated if you do not confer with others while filling in this survey questionnaire.
- Please note there are no right or wrong answers for the survey questions.
- Completing this questionnaire should take approximately 10 minutes.

Kindly respond to the questions below by circling the required alphabet and please answer all questions.

1. Which of the following types of bulbs is more energy saving?
   A. Light Emitting Diodes (LEDs)
   B. Incandescent bulbs
   C. Compact Fluorescent Lamps (CFLs)
   D. Halogen Incandescent bulbs

2. What is the ideal distance between a refrigerator and the wall?
   A. 4cm
   B. 15cm
   C. 10cm
   D. There should be no distance between the refrigerator and the wall

3. Which of the following is true for microwave ovens?
   A. Microwave ovens should be used for large portions of food
   B. The more digital displays available, the more energy efficient the microwave oven
   C. Closing the door after use reduces standby power

    D. Defrosting is not suitable for microwave oven use

4. Approximately how much heat is lost when you open the door of an oven while it is in use?
    A. 5%
    B. 35%
    C. 20%
    D. 45%

5. Which of the following statements is true when using washing machine?
    A. Wash clothes on the longest cycle and with the lowest water level depending on your needs.
    B. Wash clothes on the longest cycle and with the highest water level depending on your needs
    C. Wash clothes on the shortest cycle and with the highest water level depending on your needs
    D. Wash clothes on the shortest cycle and with the lowest water level depending on your needs

6. How often should air conditioner filters be replaced?
    A. Every one or two months
    B. Everything year
    C. Every 6 months
    D. Every 3 years

7. Which of the following is true about electric ovens?
    A. Use glass or ceramic dishes in the oven
    B. Food should be cut into smaller pieces to speed up cooking process
    C. Fan assist cooking option saves more energy
    D. All of the above

8. What is the recommended temperature for water heating in dishwashers?
    A. 115°F
    B. 75°F
    C. 100°F
    D. 150°F

9. Approximately how many hours of electricity is consumed when you leave your television on standby mode at night?
    A. 2 hours viewing time
    B. 4 hours viewing time
    C. 8 hours viewing time
    D. 10 hours viewing time

10. Which of the following statements is not true about television sets?
    A. Plasma TVs consume less energy than LED or LCD TVs
    B. Plasma TVs consume more energy than LED or LCD TVs
    C. HD TVs consume more energy than SD TVs
    D. The larger the television, the more energy it consumes

11. Which of the following type of fans is more suitable for large rooms?
    A. Tower fans
    B. Box (portable) fans
    C. Ceiling fans
    D. Desk fans

12. Which of the following is not true for notebook computers?
    A. Activating power management reduces electrical energy consumption
    B. The lower the screen brightness, the lower is the energy consumption
    C. Notebook computers consume more energy than desktop computers

D. Tracking the system usage can reduce energy consumption

13. Which of the following definitions is correct for the term kilowatt-hour?
    A. Equal to 1,000 watt-hours
    B. Unit used by utility company
    C. Measure electrical energy consumed in one hour
    D. All of the above

14. “Adjusting the brightness of televisions according to the room size can reduce its energy consumption.” Is this statement true or false?
    A. True
    B. False

15. “Higher quality settings can increase the energy consumption of laser or inkjet printers.” Is this statement true or false?
    A. True
    B. False

Appendix C

TAM Questionnaire

The following TAM questionnaire was used in the post-test activity for the user evaluation experiment.

Towards Green Consumption of Electronic Devices: *Using Augmented Reality to Improve Awareness*

This research study involves the development of an Augmented Reality application to help individuals track and reduce their energy consumption from electrical and electronic appliances. The application aims at increasing awareness on green utilization of both household and office appliances.

This project is being conducted by Middlesex University (Mauritius Branch Campus) in collaboration with the University of Mauritius, and is being funded by Mauritius Research Council.

OATH OF CONFIDENTIALITY

This is to certify that any information (written, verbal or other form) obtained during the performance of this survey will remain confidential. This includes all the information about the participants and any other confidential information being asked in this survey.

We understand that any unauthorized release or carelessness in the handling of this survey questionnaire is considered a breach of the duty to maintain confidentiality. Any breach of duty in maintaining confidentiality is liable to any legal action arising from such breach.

PLEASE NOTE

- You are not required to identify yourself and your responses shall not reveal your identification.
- Feel free to seek any clarification and ask any question(s) regarding the research project from the investigator.
- All responses will be treated in strict confidentiality and will be used solely for academic research purposes.
- Your individual response is highly valued, thus it would be appreciated if you do not confer with others while filling in this survey questionnaire.
- Please note there are no right or wrong answers for the survey questions.
- Completing this questionnaire should take approximately 10 minutes.

Please respond to each statement according to the following scale below:
(1) Strongly Disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree

	Content Organization	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
	Perceived Enjoyment					
1.	The AR application is fun to use.	1	2	3	4	5
2.	The AR application is pleasant.	1	2	3	4	5
3.	I feel a high level of enjoyment using the system.	1	2	3	4	5
4.	I feel unhappy the experience is over.	1	2	3	4	5
5.	I am willing to repeat the same experience.	1	2	3	4	5
6.	This was an interesting experience.	1	2	3	4	5
	Additional Comment:					
	Perceived Ease Of Use					
7.	Learning to use ARGY application is easy.	1	2	3	4	5
8.	I found it easy to navigate and select the different options in AR View menu.	1	2	3	4	5
9.	It was easy getting used to the AR energy application.	1	2	3	4	5
10.	Overall I found the application easy to use.	1	2	3	4	5
	Additional Comment:					
	Perceived Usefulness					
11.	Using the application would help track my electrical energy consumption more effectively.	1	2	3	4	5
12.	Using the application would enhance my awareness on green consumption of electrical devices.	1	2	3	4	5
13.	The application will help reduce my electricity bill.	1	2	3	4	5
14.	I find AR technology a useful learning tool.	1	2	3	4	5

Additional Comment:

Intention To Use

15.	I intend to use any system attributed to AR technology when it becomes commercially available	1	2	3	4	5
16.	I intend to use other related AR application to increase my knowledge on green consumption of appliances.	1	2	3	4	5
17.	Given that I had access to the application, I predict that I would use it frequently.	1	2	3	4	5

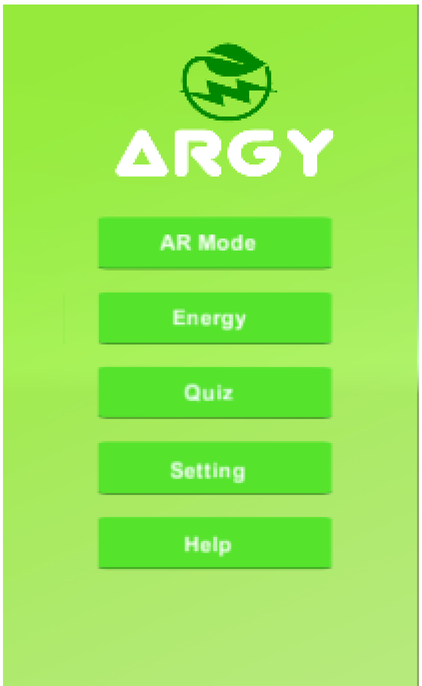
Appendix D

User Manual for ARGY Mobile Application

Starting the Application

To start the ARGY application, follow the steps given below:

1. Click on ARGY icon on the application menu of your mobile device.
2. On clicking the ARGY icon, the application starts and displays the main menu page. The main menu contains five different sub-menus to select from, namely AR Mode, Energy, Quiz, Setting and Help. The AR Mode is used to scan the environment and detect electrical and electronic appliances. The Energy sub-menu is used to view the energy consumption of detected electrical appliances. The Quiz sub-menu is used to complete the quiz questions related to green consumption behaviours. The Setting sub-menu allows for changes to be made in the setting features of the application. The Help sub-menu provides guidelines on how to use the application.



Scan an Electrical Appliance

To scan and detect an electrical or electronic appliance, follow the steps below:

1. Select the AR Mode sub-menu on the main menu screen.
2. On selecting AR Mode, the camera view of the mobile device will be displayed. To detect any electrical appliance, please ensure the corresponding image icon of that appliance is available. For example, is a projector needs to be detected, the following image icon should be scanned.

3. To scan the image icon, hover the device camera over the image such that the projector icon can be seen on the camera screen of the device.
4. When the mobile application successfully detects the image icon, different digital buttons appear on the screen, as shown in the figure below. To know whether the application has detected the correct appliance, the name of the appliance is displayed at the top of camera screen. In this example, the text is "Projector Detected".
5. To go back to the main menu, touch "Home" button on the left hand-side of the screen. This button is represented by a green home icon.

Measure Electrical Energy Consumption of Appliance

To measure the electrical consumption of an electrical appliance, follow the steps described below:

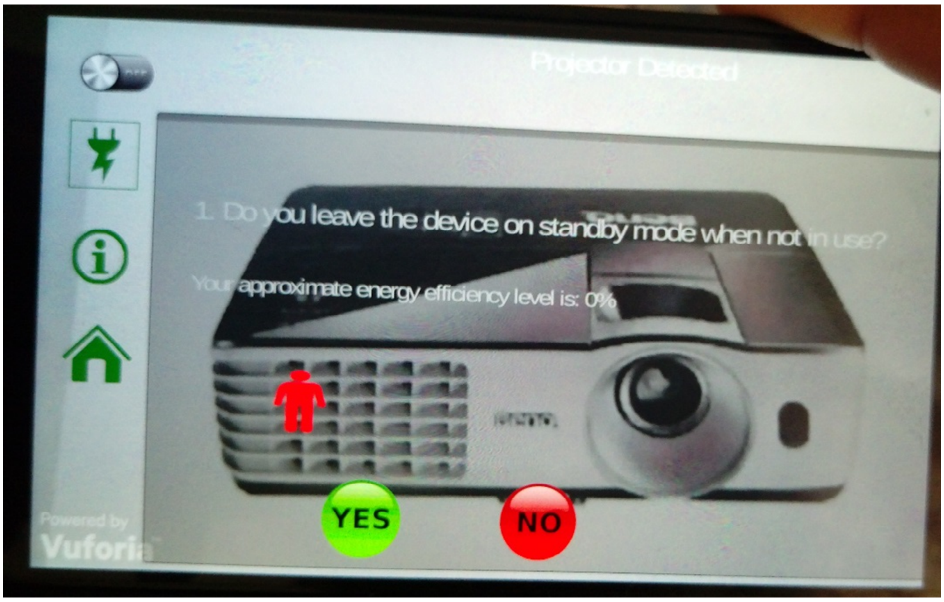
1. Select the AR Mode submenu and scan the image icon of the electrical appliance.
2. When the appliance is detected, touch the Switch button to start measuring the electrical energy consumption of the appliance. On touching the switch button, the ON button will appear. The ON button is indicated by a green colour, with the "ON" text written. When the ON button appears, the application starts measuring the electrical energy consumption and time duration during which the appliance is in use.

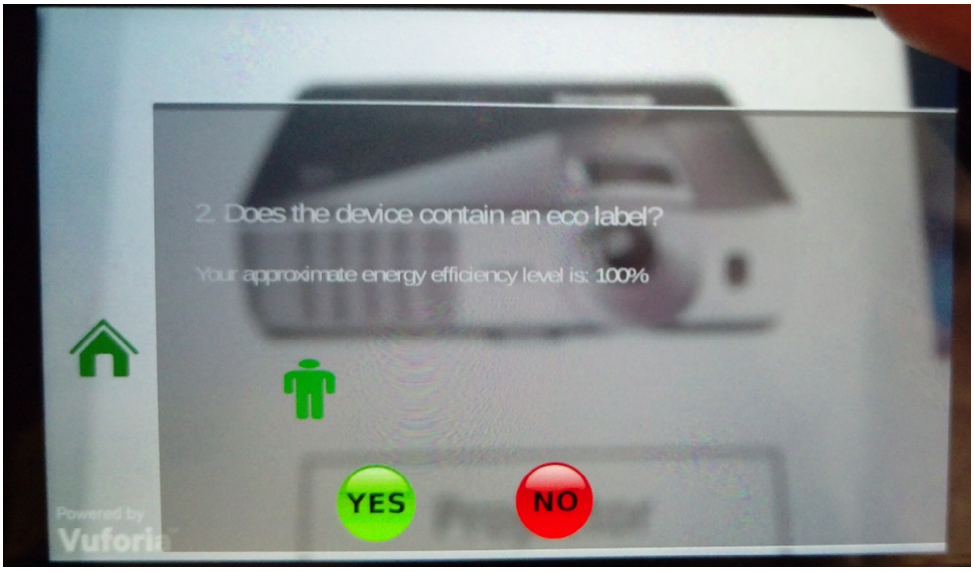
3. To stop measuring the electrical energy consumption of an appliance, touch the ON Switch button again. The button with then turn to the "OFF" state, indicated by a grey colour with the "OFF" text written.
4. To view the energy consumption and time duration the appliance was in use, the ON state should be disabled and the OFF switch will then appear. At the same time, the energy consumption given in KWh and the time duration given in hours and minutes appear at the centre of the device screen. These information are automatically saved in the local storage of the mobile device.

Assessment of Energy Efficiency Level

To assess the energy efficiency level when using the electrical appliances, follow the steps described below:

1. Open the AR Mode submenu and scan the image icon of an appliance.
2. When the application detects the application symbol, touch on the second green icon on the left hand-side of the device screen. This icon is the Energy icon and is represented by a green electrical plug image.
3. After touching the Energy button, a popup window appears at the centre of the screen. The window contains a series of questions which appear one after the other. All the questions are related to the use of the detected electrical appliance. By answering the questions, the energy efficiency level is given in the form of a percentage value.
4. The questions should be answered by touching either the Yes or No buttons which appear at the bottom of the popup window. The Yes button is a green circle and the No button is a red circle.
5. Depending on the answers given, the energy efficiency level percentage changes. The higher the percentage, the more energy efficient is the user. A colour-coded man icon is also used to give a visual representation of the energy efficiency level of the user. The colour ranges from red to green, with two other colours namely orange and yellow used in between. The green colour is used to indicate the highest energy efficiency level and the red colour is used to indicate the lowest energy efficiency level.





View Tips

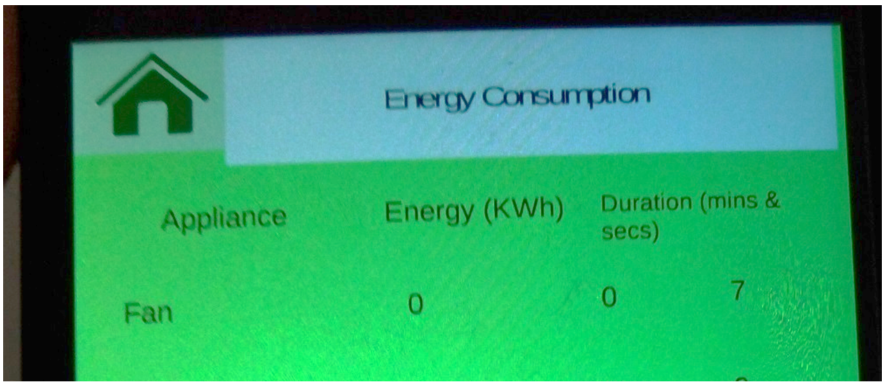
To view tips while using an electrical appliance, following the steps described below:

1. Open the AR Mode submenu and scan the electrical appliance.
2. When the application detects the appliance symbol, select the third green button on the left hand-side of the camera screen. This button is called the Tip button and is presented by a green exclamation mark icon.
3. When touching the Tip button, a list of different information, tips, is displayed at the centre of the screen.

View Energy Consumption and Time Duration of All Detected Electrical Appliances

To view the energy consumption and time duration of any electrical appliances which have been scanned and activated, follow the steps described below:

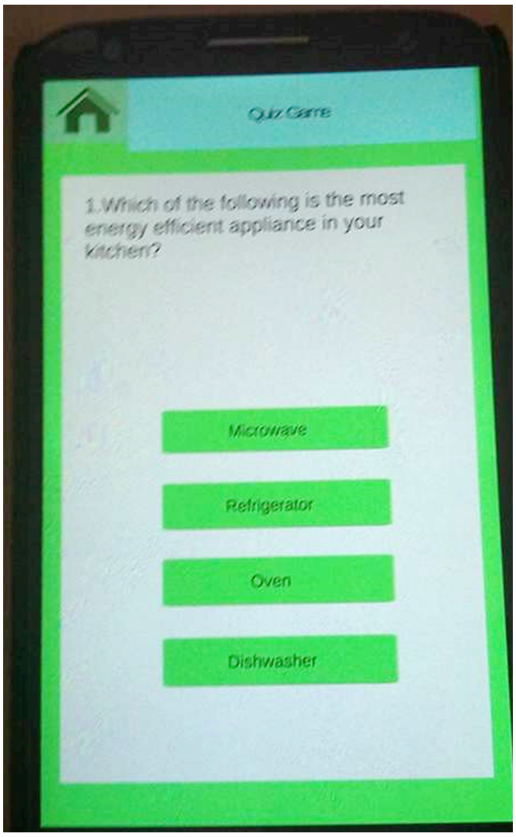
1. Open the Energy submenu from the main menu home screen.
2. On selecting the Energy submenu, the next screen which appears displays a list of all the electrical appliances which have been in use, along with their respective energy consumption value and time duration.
3. To go back to the main menu, the Home button at the top of the page needs to be selected.



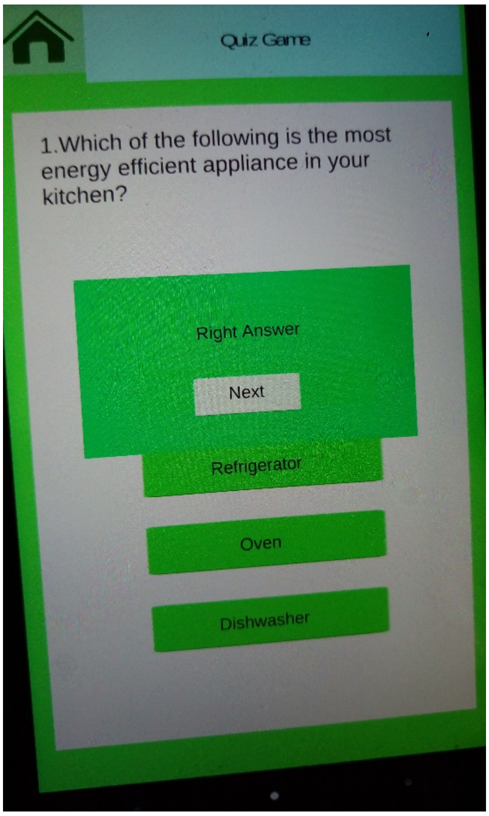
Complete the Quiz questions

To do the quiz, follow the steps described below:

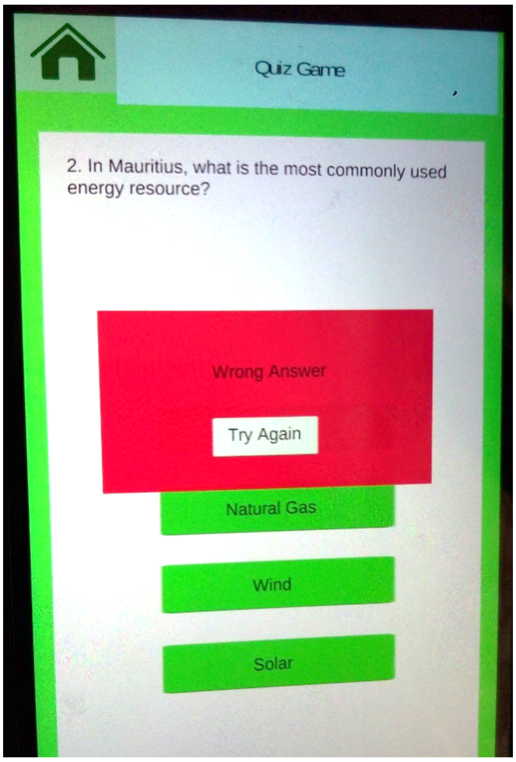
1. Select the Quiz submenu from the main menu screen.
2. When the Quiz menu is selected, the following screen appears. The screen shows the first questions, along with the four options to choose from. Only one answer is correct.



3. When the correct answer is chosen, the following screen appears. To go to the next question, the “Next” button needs to be selected.



4. When the wrong answer is chosen, the following screen appears. The "Try Again" button needs to be selected to continue with the quiz, and try the same question till the correct answer is obtained.



To View the Application Guideline

To view the guidelines on how to use the different features of the application, follow the steps described below:

1. Open the Help submenu from the main menu home screen.
2. When the Help submenu is selected, the following screen appears. All the details on how to use the application are described.