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Enhancing Awareness on Green Consumption of Electronic Devices: The Application of Augmented Reality

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Abstract— **During the past few decades, the adoption of electronic devices (e.g. television sets, computers, etc.) in both households and businesses has brought immense benefits to human beings. However, their increasing utilization adversely contribute to a rise in energy consumption, electronic waste and is even detrimental to human health and to the environment. As such, it is essential that human beings undertake actions to reduce the risks and damages caused by these devices to the environment. Concurrently, studies have revealed that a lack of knowledge is considered amongst the important barriers 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 (AR). However, this technology has not been exploited to improve awareness on environmentally sustainable use of electronic devices. As such, this paper investigates the application of AR to improve awareness on green consumption of electronic devices by delving into key research questions pertaining to technology acceptance, knowledge gains and associated barriers to adoption. In this endeavor, an AR-based mobile application was implemented to enable individuals learn energy consumption of electronic devices being used at home and offices. The research questions were answered following application of the Technology Acceptance Model and by conducting multiple-choice based tests. Results principally indicated a positive correlation between AR and learning enhancement on green consumption of electronic devices.**

Keywords— Green Consumption, Augmented Reality, Awareness Improvement, Electronic Devices, Technology Acceptance.

1. INTRODUCTION

Since the last few decades, the world has entered an era of unprecedented digital disruption in the form of technological innovations and major evolutions in the ways people have adopted technologies within both businesses and households (Crosbie, 2008; Manyika, et al., 2013). This is due to the diverse benefits that adoption of technology has brought in terms of improved productivity, entertainment and communication, among others (National Research Council, 2003). In 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). As such, although television sets, washing machines, computers and mobile phones are only a few among the list of electronic devices currently present within households and business organizations, adoption of these devices are expected to grow (Future Market Insights, 2016). However, these electronic devices have already been considerably contributing to an increase in energy consumption and their expected growth is projected to further adversely impact the environment (EIA, 2011; Bekaroo, et al., 2016). This is principally because these devices are power-dependent and the generation of electricity is known as a key contributor to climate change due to the use of non-renewable sources (e.g. coal or oil) that release carbon dioxide, pollutants and Sulphur into the atmosphere (Murugesan, 2008). Furthermore, increase 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) and 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, it has become essential 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 recognized solution to mitigate the above problems is to consume electronic devices in an environmentally sustainable or green manner (Shina, 2008). In other words, these devices should be utilized in such a way to avoid causing damage to the natural ecosystem while helping to maintain environmental sustainability. For this, end users need to be aware of the techniques and best practices available in order to be able to use their electronics in an environmentally sustainable way (He & Greenberg, 2008). 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; Uddin & Rahman, 2012). However, even with the availability of these resources, awareness on energy efficient use of computing and electronic devices remains an important barrier that needs to be further addressed (Bekaroo, et al., 2016; Poortinga, et al., 2006; Vandenbergh, et al., 2011). Generally, knowledge has been argued amongst the important barriers to the adoption and implementation of environmentally sustainable actions and limited knowledge can considerably obstruct the implementation process of greener actions needed to benefit the environment (Wabwoba, et al., 2012). Moreover, although personal engagement is often claimed to be of utmost importance when it comes to the implementation of environmentally sustainable actions, this factor is considered to be limited among users (Mattern, et al., 2010). One emerging technology, which has shown the potential to better engage learners, is Augmented Reality (AR) (Dede, 2009; Wagner, et al., 2005).

1.1 Augmented Reality and Self Learning

The mixed reality concept is used to classify the diverse reality technologies found in the reality-virtuality continuum (Bimber & Raskar, 2005). In this continuum, real environment relates to the natural world where objects obey physical laws whereas virtual environment is where computer graphics are utilized to create 3-dimensional virtual environment (Pan, et al., 2006). Different types of environments are found on the continuum including augmented reality and virtual reality (Milgram & Kishino, 1994). On one hand, virtual reality involves totally immersing all the senses of the user in order to create the effect of fully immersive virtual experience (Burdea & Coiffet, 2003). On the other hand, augmented reality gives room to the coexistence of virtual elements in the real world and allows for interaction with real objects as well (Antonacci, et al., 2008; Pan, et al., 2006). There are three characteristics, which are fundamental to an augmented reality interface, notably, there should be a combination of real and virtual, the interface should be interactive in real time, and the system should be three-dimensional (Azuma, 1997). This technology has been explored and successfully implemented in various domains, such as museums (Johnson, et al., 2011) and higher education (Martin-Gutierrez, et al., 2012). 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). This technology 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). Moreover, 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). Furthermore, AR also has the potential to make self-learning more engaging and robust for any individuals (Zaman, et al., 2009) and is considered as one of the most popular approaches to improve self-learning amongst students (Kose, et al., 2013; Sayed, et al., 2011).

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

Although AR has been successfully used to improved self-learning, limited number of AR-based applications are available that focus on promoting environmentally sustainable consumption of such appliances. In order to identify these tools, a query was initially made using Google for relevant keywords. This search engine was chosen because it prioritizes results based on highest relevancy as well as employs different techniques in order to enhance search quality via page rank calculation, anchor text, and other important features (Grin & Page, 1998; Lavania, et al., 2013). Following the screening process, only three relevant tools were identified.

The first one is Dia Saves Energy, which is freely available on both Android and iOS platforms (Spectre, 2015). Although this tool aims to raise awareness on energy conservation within households, it is limited to Arabic language only as it was developed as part of an energy conservation campaign in Saudi Arabia. Moreover, the application was designed for a limited number of electronics as well. Similarly, 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 (Pan, et al., 2012). The system utilizes virtual clouds of different colors and sizes to indicate the energy efficiency status of different energy-consuming devices. However, no user reviews of the application are available as the tool is not readily accessible. Likewise, Energiency is an industrial application which allows users to embody in real time an operator in charge of manufacturing dairy products by using as little energy as possible (Bretagne Commerce International , 2015). Although the application displays energy savings and ways of reducing the electrical energy consumption from manufacturing processes, it is not meant for home or office electronics. As such, related applications reviewed are either prototypes or cannot be applied for key electronic appliances used at homes.

Because of limitations of existing applications, different aspects relating to the application of AR to improve awareness on green consumption of electronic devices are yet to be investigated. First of all, understanding the conditions under which technology is accepted or not is an important issue to comprehend key issues affecting future adoption (Venkatesh & Morris, 2000). Technology acceptance here relates to the way by which people accept and perceive the use of technology (Legris, et al., 2003) and is essential to study since it provides sound predictions of usage by connecting behaviors to attitudes and beliefs (ease of use and usefulness) that are also consistent temporally and in context with behavior of interest (Wixom & Todd, 2005). So far, no study assessed such acceptance of AR towards promoting awareness on green consumption of electronic devices and this gap is investigated through RQ1. Furthermore, no assessment has been conducted about whether the utilization of augmented reality can effectively contribute to any knowledge gain in the same area and this is addressed in RQ2. As discussed earlier, knowledge gain is essential to study since knowledge is among the key aspects to promote adoption of environmentally sustainable actions (Wabwoba, et al., 2012). Moreover, the key barriers that limit the application of Augmented Reality towards enhancing awareness on green consumption of electronic devices are yet to be unveiled (RQ3), in order to enable the research and development community to investigate and develop effective solutions. As such, the following research questions listed below become important to study:

RQ1: To what extent is Augmented Reality accepted as technology to promote awareness on green consumption of electronic devices?

RQ2: How effective is Augmented Reality towards improving awareness on green consumption of electronic devices?

RQ3: What are the key barriers that limit the application of Augmented Reality towards enhancing awareness on green consumption of electronic devices?

This paper investigates the application of AR to improve awareness on green consumption of electronic devices by delving into key research questions pertaining to technology acceptance, knowledge gains and associated barriers to adoption. Findings presented in this study are expected to be beneficial to different stakeholders. First of all, the paper is intended to help policy makers in understanding the prospects of augmented reality towards enhancing awareness on environmentally sustainable consumption of electronic devices. Additionally, manufacturers of electronic devices could consider application prospects of this technology in their innovations. Also, the research and development community could further build-up on limitations unveiled in this study.

2. METHODOLOGY

In order to achieve the purpose of this paper and to answer RQ1-RQ3, an AR-based tool named ARGY was designed and developed due to the limitations of existing tools in terms of availability and features. ARGY aims to improve awareness of end-users towards promoting consumption of electronic devices in a greener manner. As key features, this tool enables end-users to:

- Scan their environments and automatically detect electronic appliances present with the camera view of mobile phones.
- Display the amount of energy consumed by an appliance at any given time.
- Obtain details on how energy efficiently the appliance is being utilized.
- Obtain tips on how to reduce the energy consumption of an appliance.
- Calculate total daily energy consumption for all electronic appliances being used in the given environment.
- Assess user knowledge using an integrated quiz.

The implementation of ARGY and the method used to answer the research questions investigated in this paper are discussed next. This starts with explanation on the adopted taxonomy of electronic devices by ARGY followed by describing energy efficiency assessment mechanism used. Then, the implementation of ARGY is described before elaborating on the method used to answer the research questions investigated.

2.1 Taxonomy Selection

Since the 1990s, the amount and types of miscellaneous electrical and electronic products found in buildings have increased considerably (Nordman & Sanchez, 2006). In order to properly manage, organize and provide accurate information on these devices, there is a need for their proper categorization, or for a taxonomy. Taxonomies, which are classification systems for the identification of content types and the relationships between these contents, are important as guide especially when conducting and synthesizing research (Earley, 2011). A few taxonomies have been proposed that provide an effective insight on the list of electrical and electronic devices present in homes and office buildings. These taxonomies have varying granularities where higher granularity meaning higher level of detail in terms of groups and categories of appliances and lower granularity referring to the opposite. One such taxonomy was proposed by Nordman and Sanchez (2006) and is based on miscellaneous and low power products focusing on electricity usage from both residential and commercial buildings (Nordman & Sanchez, 2006). This taxonomy however has high granularity thus making it complex. Another taxonomy was proposed by Lam, et al., (2007) is based on load signatures to categorize electrical appliances. Load signature here relates to 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). However, this taxonomy has not been upgraded with newer types of devices such as television boxes and Raspberry Pi, amongst others, which are being used in households. Between both taxonomies, the one proposed by Lam, et al., (2007) was chosen for ARGY due to its relevance and lower granularity in terms of categories.

Table 1 - Taxonomy by Lam, et al., (2007)

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 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	

The adopted taxonomy illustrated in Table 1 is split into 9 different groups where the left column shows the main group of appliances and the right column depicts the sub-group for each main group to show the appliances present within each main group. In this taxonomy, grouping has been done based on load signatures of electrical appliances where Group 1 consists of appliances with resistive loads, including kettle, vacuum cleaner, air conditioner, among others. Group 2 contains appliances with inductive loads including refrigerator and dehumidifier whereas Group 3 consists of appliances that operate in stand-by mode including, liquid crystal display (LCD) television. Moreover, Group 4 contains loads with asymmetric trajectories such as hair dryer whilst Group 5 consists of self-intersected trajectories like microwave ovens. Group 6 and Group 7 both contain power electronic loads but the ones in Group 6 have a larger area of left and right segments than that of Group 7. Finally, Group 8 consists of power electronic appliances operating in stand-by mode whilst Group 9 contain the other devices not forming part of the other groups, such as, projector and washer.

2.2 Formulation of Energy Efficiency Assessment Mechanism

As energy efficiency improvement has been regarded as an essential way of addressing both energy security and environment concerns (Tanaka, 2008), enabling the end user to assess how efficiently he/she is utilizing a selected electronic device becomes important and is thus a feature of the proposed tool. As there is a lack of standardized quantitative metrics for energy efficiency assessment (Uddin & Rahman, 2012), a list of questions specific to each device and related to the best practices while using the individual appliances was formulated as approach to assess energy efficiency assessment by ARGY. The questions are close-ended questions, with Boolean type answers and the choice of basing all the questions pertaining to best practices related to the appliances enables a better understanding on how much the users adopt energy efficient behaviors and practices while using electrical appliances. The answers to the questions are then aggregated to determine an approximate percentage of the energy efficiency utilization of the appliance. Additionally, to simplify interpretation, the calculated energy efficiency performance is represented by a color-coded figure similar to the European Union energy label, where green represents the most energy-efficient utilization and red the least efficient (Gov.uk, 2013). Energy efficiency performance along with the color code is illustrated in Table 2.

Table 2 – Energy efficiency performance

Energy efficiency score	**Label**	**Description**
0%-25%		Inefficient utilization of device
26%-50%		Device utilized with satisfactory efficiency
51%-75%		Efficient utilization of device
76%-100%		Very efficient utilization of device

2.3 Prototype Implementation

For the development of ARGY, Android was chosen as targeted operating system because it was recently regarded as the most popular one in the world (Network World, 2017). As this study was focused on answering RQ1-RQ3, extension to other platforms were not relevant. For implementing the tool, a comparative analysis of existing Augmented Reality software development kits (SDK) was performed. In this process, Vuforia[1], Wikitude[2], ARToolkit[3] and In2AR[4] SDK were analyzed. 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 as this SDK was also used in previous similar research involving development of AR tools (Xiao & Lifeng, 2014). The implementation of the Android application was done entirely in Unity (version 5.0.0f4) (Unity Technologies, 2016) and the Vuforia plug-in was used.

Following selection of the SDK, decision had to be taken between the use of marker-based or marker-less approach for target detection and identification. In marker-based tracking, digital images or markers are used to identify objects and gauge their relative orientation to the camera itself. In this process the digital image or marker is encoded with information which is in turn translated by a complex software so as to identify or produce a 3D object. On the other hand, marker-less based tracking does not involve the use of markers and thus, objects that are not directly provided to the application beforehand are recognized. Since there are various limitations with marker-less based tracking of large and shiny 3D objects (Vuforia Developer Portal, 2017), such as refrigerators or washing machines, the marker-based approach was chosen. The use of the marker-based approach also meant that users would need to print and stick appropriate markers to the electronic device that needs to be augmented. 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). A list of different markers representing electrical and electronic appliances was created based on the selected taxonomy as given in Table 1. The main criteria for choosing the images was a good contrast in colors and patterns to enable the Vuforia plug-in to recognize the images easily. Some of these markers are illustrated in Figure 1.

Figure 1 - List of markers

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[1] Vuforia, available at: https://www.vuforia.com/
[2] Wikitude, available at: https://www.wikitude.com/
[3] ARToolkit, available at: https://artoolkit.org/
[4] In2AR, available at: https://www.beyondreality.nl/in2ar/

The user interface was then 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. In the application, there are five different menu items, namely, AR Mode, Energy, Quiz, Settings and Help as depicted in Figure 2. Amongst these menu items, AR Mode 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 assess their energy efficiency utilization. Additionally, the Energy menu item allows the user to view a list of all the appliances in active use, along with the total energy consumption and the Quiz contains a list of twenty randomized questions for users to answer and test their knowledge on eco-friendly habits, as shown in Figure 3.

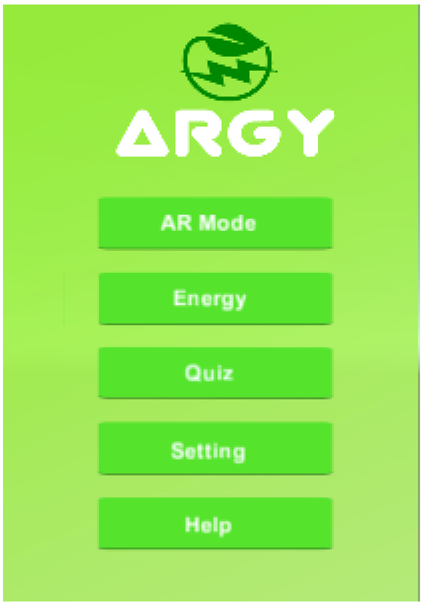

Figure 2 - Menu items in ARGY

Figure 3 - Quiz mode

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, a digital overlay is displayed. As an example, 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, as shown in Figure 4.

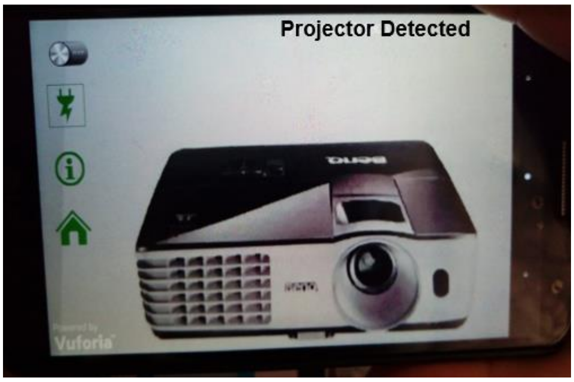

Figure 4 - ARView Screen when projector is detected

Once a target or electronic device has been identified, an important feature of ARGY is to provide end-users with an estimate of the energy consumed by that appliance. To achieve this, the user needs to activate the energy display feature using the toggle button available as the first option on the top left corner in the toolbox as shown in Figure 4. Upon activation, a timer is started by the system to be used for energy calculation. Also, 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 type of appliance. Based on the power and timer, the energy consumption is calculated using the following formula:

$$Energy\ Consumption\ (in\ kWh) = \frac{Power\ (Watt) \times Time\ (hour)}{1000}$$

The energy consumption value is given in kWh, and the time during which the appliance was in use are also indicated on the interface, as shown in Figure 5. Both values are refreshed every second so that the end user can get real-time information.

Figure 5- ARView Screen when projector is detected

Furthermore, ARGY also permits end users to assess how efficiently their electronic devices are being utilized from an energy perspective. As discussed earlier, a series of questions pertaining to eco-friendly practices are asked in the process and the appropriate label is shown, as depicted in Figure 6. Additionally, in the AR Mode, the user can view tips or best practices on how to consume particular appliances in an energy efficient manner when clicking the information button shown in Figure 5. Moreover, the user can view energy consumption of a list of devices at the same time through the Energy menu item as in Figure 2.

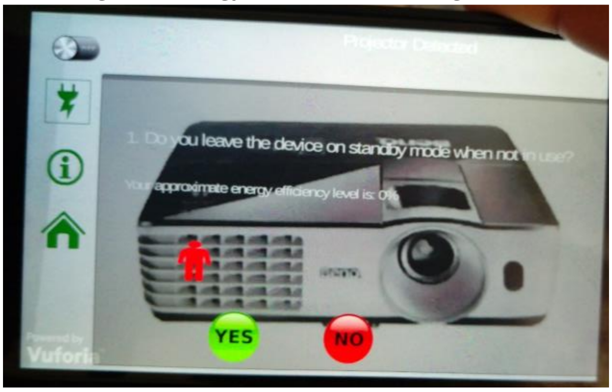

Figure 6 - Energy Efficiency Assessment

2.4 Evaluation Method

For answering the research questions, a feasibility study was conducted. In order to assess the level of technology acceptance (RQ1) that the AR application has on the participants, the Technology Acceptance Model (TAM) was chosen. TAM was proposed by Davis (1989) and Davis, et al. (1989) in order to investigate the reasons for users to accept or reject information technology (Davis, 1989; Davis, et al., 1989). This model is also an adaptation of the theory of reasoned action (Fishbein & Ajzen, 1975), proposed to explain and predict the behavior of people in a particular situation. The major purpose of TAM is to provide a means for tracing the impact of external variables on internal beliefs, attitudes, and intentions and for this, different factors in explaining use of a system are referred (Legris, et al., 2003). For this study, TAM was chosen since it is the most experimentally validated and widely used among all other models including the Innovation Diffusion Theory or Unified Theory of Acceptance and Use of Technology (King & He, 2006). Furthermore, this model has also been used in the evaluation of various research related to AR (Haugstvedt & Krogstie, 2012; Balog & Pribeanu, 2010; Wojciechowski & Cellary, 2013; Rauschnabel & Ro, 2016). Since most of user acceptance studies are dependent upon the technologies being analyzed, the TAM model is combined with other specific constructs which are applicable to the technologies being evaluated (Chesney, 2006). Constructs here refer to weight related factors which help in assessing the use and acceptance of the technology. Four important constructs were found important to be assessed in the endeavor to evaluate technology acceptance, namely, perceived enjoyment, perceived ease of use, perceived usefulness and intention to use (Davis, 1989; Davis, 1993), as described in Table 3. Each construct is assessed through different items which have been adapted from different studies involving TAM (Davis, 1989; Davis, 1993; Landry, et al., 2006; Chang, et al., 2012; Kim & Garrison, 2009). The measured items for each construct are also listed in Table 3.

Table 3 – Implemented Constructs for TAM

Construct	**Definition**	**Measured item**
Perceived Enjoyment	The level to which an activity carried out through the use of a particular technology is deemed enjoyable (Chesney, 2006).	The AR application is fun to use.
		The AR application is pleasant.
		I feel a high level of enjoyment using the system.
		I do not feel unhappy the experience is over.
		I am willing to repeat the same experience.
		This was an interesting experience.
Perceived Ease of Use	The level to which users of the system feel its use will be effort free (Davis, 1989).	Learning to use ARGY application was easy.
		I found it easy to navigate and select the different options in AR View menu.
		It was easy getting used to the AR energy application.
		Overall, I found the application easy to use.
Perceived Usefulness	The level to which users feel that utilizing the technology will aid in enhancing their task accomplishments (Davis, 1989).	Using the application would help track energy consumption of my appliances more effectively.
		Using the application would enhance my awareness on green consumption of electrical devices.
		The application will help reduce my electricity bill.
		I found AR technology a useful learning tool.
Intention to Use	The level to which users have devised conscious intentions to utilize or not utilize certain specific future practices (Davis, 1989).	I intend to use any system attributed to AR technology when it becomes commercially available
		I intend to use other related AR application to increase my knowledge on green consumption of appliances.
		Given that I had access to the application, I predict that I would use it frequently.
		Assuming I had access to the application, I intend to use it.

Secondly, it was essential to assess whether the adoption of AR effectively leads to an increase in knowledge from the users on green consumption of electrical appliances (RQ2). For assessing knowledge gain on the topic, a common approach is to conduct a pre-test and post-test before analyzing the collected data (Lundberg, et al., 1980; Ball & Blachman, 1991). Due to the nature of the research, 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. Finally, to unveil the limitations of the application of AR (RQ3), feedback from participants following utilization of the tool were targeted.

Once the evaluation approach was chosen, the data collection instrument was designed. This involved the use of 3 questionnaires, namely, for the TAM, pre-utilization test and post-utilization test. The TAM questionnaire consisted of 18 questions (using a Likert-5 scale) split into four key sections based on the constructs described in

Table 3. For the pre-utilization and post-utilization tests, 2 multiple-choice questionnaires (MCQ) were prepared consisting of 15 questions related to green practices and consumption of electrical and electronic appliances. Each question was assigned different options, out 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. The reason behind not changing the questions was to analyze any knowledge gains in the post-utilization test. These questions are given in Table 4.

Table 4 – List of Multiple Choice Questions

Number	Question	Answers to choose from
1.	Which of the following types of bulbs is more energy saving?	A. Light emitting diodes B. Incandescent bulbs C. Compact fluorescent Lamps 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 the door of an oven is opened 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

As highlighted by Nielsen (1994), useful results can be achieved by non-expert users provided these users understand what is being evaluated (Nielsen, 1994). As such, non-expert users in the form of students aged between 19 and 24 who were unfamiliar with the technology were targeted. This group was chosen because of predominance in terms of smartphone ownership while also being an important user of different electronic appliances (Pew Research Centre, 2017). In addition, studying this young population group could reveal insightful information on the adoption and prospects of such technologies (Bekaroo, et al., 2016). As recruitment method, the Hallway or Guerrilla Testing method was chosen because of its simplicity. This method involves asking anyone or passers-by to participate also increases the chances of having an unbiased evaluation (Interaction Design Foundation, 2016). Using this recruitment method, students from Middlesex University (Mauritius Branch Campus) were targeted using the non-probabilistic sampling technique of convenience. In addition, only participants who were utilizing Android based smartphones were targeted for compatibility reasons with the implemented AR-based tool. In this process, 52 students were approached where 9 of them could not participate as the group was not using an Android based phone. Also, 3 students chose not to participate as this small group mentioned to be taken up with university projects and coursework. As such, following the screening and recruitment processes, 40 students from Middlesex University (Mauritius Branch Campus) participated in the study and this exceeds the minimum number of test users required for such quantitative studies (Nielsen, 2012; Venkatesh & Bala, 2008).

As procedures, participants were briefly informed about the research study and process. The reason for providing brief training was to improve chances of identifying issues, as highlighted in a previous study (Castillo, et al., 1998). After providing written informed consent, the first MCQ test (pre-test) was conducted with the participants to assess their current knowledge on green practices with regards to electronic devices. Once the test was completed, each participant had to immediately return their script to the investigator to ensure that answers are not verified before submitting the questionnaire. Then, the mobile application was given to each participant for installation while also ensuring that the application was running perfectly following set-up. Additionally, all the image targets were printed and cut into square pieces and given to them. Participants were told to either place the image stickers next their electrical appliances, or stick them on the appliances if possible. Then, the participants utilized the AR based system within a lab that contained some household and office electronics to make sure every feature is operational. Following lab use, participants were then given a week to utilize ARGY, to understand energy consumption of electronic devices and to learn about the different green energy practices through the application. During this week, participants were also advised not to refer to other sources of information (e.g. websites and books, among others) to read further information on energy consumption of devices. Also, the group was asked to take pictures of their electronics with tags attached to show proof of utilization of the tags. One week later, the participants were convened for the post-utilization test to complete the second MCQ test in order to assess knowledge gains of the participants after using the application. During the same session, participants had to show some proof of using ARGY in their respective houses by showing pictures captured. This measure was essential to ensure that the participants used ARGY before the post-utilization test. Following this verification, participants had to fill-in the TAM questionnaire in order to give feedback on technological acceptance of ARGY (RQ2), in addition to feedback on adoption barriers (RQ3). Once a questionnaire was completed, the research team thoroughly checked the document to ensure its validity and any anomaly found was resolved instantly. Finally, the data collected were input on SPSS for statistical analysis and the reliability of the collected data was checked. The Cronbach's alpha for the TAM related variables was 0.88 thus showing consistency of collected data.

3. Results and Discussions

The results of the study are discussed as follows, starting with technology acceptance (RQ1) followed by knowledge gain (RQ2) and associated barriers to adoption (RQ3).

3.1 Technological Acceptance

Through the TAM, four aspects namely, perceived enjoyment, perceived ease of use, perceived usefulness and intention to use were evaluated in order to assess technological acceptance of the application of Augmented Reality to promote awareness on green consumption of electronic devices (RQ1). Results pertaining to these four constructs are discussed as follows.

- ***Perceived Enjoyment***

This aspect relates to the extent to which the activity of utilizing the system is perceived to be enjoyable in its own right (Davis, et al., 1992) and to assess this aspect, 6 criteria were considered as shown in Table 5. Among these criteria, the majority of participants agreed that the AR application was fun to use because respondents particularly enjoyed the experience utilizing their camera to identify appliances and obtained meaningful information pertaining to energy use and efficiency. Moreover, a significant number of participants either agreed or strongly agreed that the application was pleasant and this was mainly due to the end user interface provided. However, when asked whether a feeling of a high level of enjoyment was experienced when using the system, an important group of participants remained neutral and this was mainly because the application caused the device to heat-up and this was due to the use of the camera which analyses images to identify the pre-defined targets in real-time mode. In addition, a small group of participants were unhappy that experience was over whilst an important percentage remained neutral. This was so because the participants perceived that the application could be utilized again in the future as the group already had a copy. This also led to the majority of the participants who were willing to repeat the same experience as a good number of participants found the experience interesting. Overall, perceived enjoyment has been regarded form of intrinsic motivation (Balog & Pribeanu, 2010) and positive results were obtained for the pleasure and inherent satisfaction derived from the use of AR to improve awareness on green consumption of electronic devices.

Table 5 – Perceived Enjoyment Results

Measured item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*	*Variance*	*Standard Deviation*
The AR application is fun to use.	2.5%	15.0%	25.0%	55.0%	2.5%	0.76	0.87
The AR application is pleasant.	2.5%	15.0%	30.0%	40.0%	12.5%	0.97	0.99
I feel a high level of enjoyment using the system.	5.0%	20.0%	42.5%	27.5%	5.0%	0.89	0.94
I do not feel unhappy the experience is over.	12.5%	2.5%	42.5%	2.5%	40.0%	0.67	0.82
I am willing to repeat the same experience.	0.0%	12.5%	25.0%	57.5%	5.0%	0.61	0.78
This was an interesting experience.	2.5%	15.0%	15.0%	52.5%	15.0%	1.01	1.01

- ***Perceived Ease of Use***

Ease of use was another important aspect assessed as part of the evaluation and results showed that most of the participants either agreed or strongly agreed that learning to use ARGY application was easy. This was also due to the small number of features in the application. Only a small percentage disagreed with this statement and 2 participants mentioned to have found the application difficult to use. These participants were also utilizing a low resolution camera which made it challenging to detect the image targets and required different attempts for successful target recognition. Furthermore, a smaller group of participants found it easy to navigate through the different menus and a more significant group of participants agreed that it was easy to get used to the application. Finally, most participants either agreed or strongly agreed that the application was easy to use and this overall positive ease of use results also implies that users of the system were able to utilize the AR based system with reduced effort. Results on the perceived ease of use are given in Table 6.

Table 6 – Perceived East of Use Results

Measured item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*	*Variance*	*Standard Deviation*
Learning to use ARGY application was easy.	0.0%	2.5%	32.5%	52.5%	12.5%	0.50	0.71
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%	0.50	0.71
It was easy getting used to the AR energy application.	0.0%	10.0%	15.0%	62.5%	12.5%	0.64	0.80
Overall I found the application easy to use.	2.5%	12.5%	22.5%	42.5%	20.0%	1.05	1.03

- ***Perceived Usefulness***

The results for this construct are given in Table 7 and it was found that the majority of participants perceived that the application would help keep track of the energy consumption of their appliances more effectively. Even though the value provided was an estimate, participants felt more engaged with learning the energy consumption of each device to better understand how each one contributes to monthly electricity bills. Also, a significant percentage of participants agreed or strongly agreed that the application enhanced their awareness on green consumption of electrical devices, as compared to a considerably lower number of respondents who disagreed with this. The group who disagreed with this statement mentioned that only limited information was provided as overlay, which could be extended. Moreover, a good number of participants were neutral to the fact that the application would help reduce the electricity bill, while a slightly larger group was favorable to this statement. The participants who were neutral to this statement felt that the system only provided a means to learn about how to reduce consumption whilst there is no feature to directly control implemented actions that could help reducing electricity bills. Finally, an important number of participants found the technology a useful tool to improve awareness.

Table 7 – Perceived Usefulness Results

Measured item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*	*Variance*	*Standard Deviation*
Using the application would help track energy consumption of my appliances more effectively.	0.0%	7.5%	27.5%	57.5%	7.5%	0.54	0.74
Using the application would enhance my awareness on green consumption of electrical devices.	0.0%	10.0%	35.0%	47.5%	7.5%	0.62	0.78
The application will help reduce my electricity bill.	0.0%	12.5%	40.0%	45.0%	2.5%	0.55	0.74
I found AR technology a useful learning tool.	0.0%	17.5%	30.0%	50.0%	2.5%	0.65	0.81

- ***Intention to Use***

Results showed that an important number of participants was attracted by the AR technology and intend to use any related system in the future and these were particularly first time users of this technology. Moreover, a more significant number intend to use AR related application to increase their knowledge on green consumption of appliances where only a smaller group disagreed with this statement. Finally, most participants expressed their intention to use the application provided they would continue to have access to it after the evaluation phase. In general, there was a positive response to the intention to use the application in the future as depicted in Table 8. This could also be attributed to the positive results obtained for perceived enjoyment where previous studies showed a co-relation between both variables (Balog & Pribeanu, 2010; Wojciechowski & Cellary, 2013; Chung, et al., 2015).

Table 8 – Intention to Use Results

Measured item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*	*Variance*	*Standard Deviation*
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%	0.87	0.93
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%	0.65	0.81
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%	0.76	0.87
Assuming I had access to the application, I intend to use it.	0.0%	0.0%	32.5%	57.5%	10.0%	0.38	0.62

Overall, the application of augmented reality was positively accepted by end-users in the endeavor to improve awareness on green consumption of electronic devices (RQ1). Application of the TAM showed that on average 55.0% of participants agreed or strongly agreed about the different criteria assessed under the 4 constructs thus highlighting an overall positive acceptance. Among these constructs, the highest mean acceptance percentage was achieved for perceived ease of use. On the other hand, a slightly lower acceptance was achieved for perceived enjoyment particularly because of the image analysis process through the camera, which caused the mobile phone to heat-up. Additionally, acceptance was also impacted by the frequency of which devices had to be activated and deactivated so as to obtain energy values. Out of the 20 different stickers given to the participants as shown in Figure 1, 9 different ones were mentioned to be used by the participants and some devices like light bulbs and television set had to be activated and deactivated on the system frequently so as to obtain energy values. The distribution of the mean technological acceptance of the 4 constructs is given in Figure 7, showing the percentage of the sum of agreed and strongly agreed for each construct.

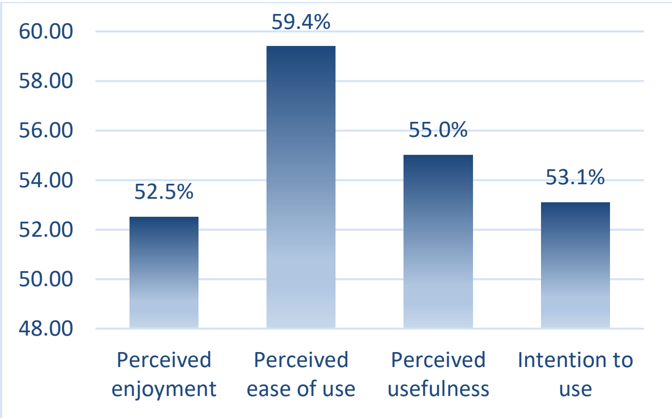

Figure 7 – Technology Acceptance

3.2 Knowledge Gains

In order to assess knowledge gains (RQ2), pre-utilization and post-utilization tests were conducted as discussed earlier. In the pre-utilization test conducted among the participants, the average score achieved by the participants was 40.8%, as shown in Figure 8. In this test, it was observed that the participants had challenges in answering questions that had quantitative values as answers, e.g. *approximately how many hours of electricity is consumed* *when the television set is left on standby mode at night? Or approximately how much heat is lost when the door of an oven is opened while it is in use?* However, these results were improved in the post-utilization test. In the same test, 100% of participants showed at least some improvements in their score and the average score for correct answers represented an increase of 38.2% as shown in Figure 8, thus showing a positive knowledge gain. This was confirmed through the Paired Samples T Test which gave 10.99 as t-value and $p<0.01$ thus implying a statistically significant difference between the two MCQ tests conducted. This improvement in the results could also be attributed to the active utilization of ARGY throughout the week thereby indicating that the use of the prototype has helped participants to learn more on the green practices regarding different appliances. As such, due to the positive knowledge gains, it could be deduced that the application of Augmented Reality was effective towards improving awareness on green consumption of electronic devices (RQ2). This knowledge gain could positively translate to more environmentally sustainable behavior as awareness has been fundamentally linked to human behavior from a psychological perspective (Hartley, et al., 2015; Rees & Pond, 1995).

Table 9 –Performance of Participants in Both Tests

Number	Question	Pre-utilization Test		Post-utilization Test	
		Count	%	Count	%
1	Which of the following types of bulbs is more energy saving?	14	35.0	31	77.5
2	What is the ideal distance between a refrigerator and the wall?	17	42.5	31	77.5
3	Which of the following is true for microwave ovens?	20	50.0	36	90.0
4	Approximately how much heat is lost when the door of an oven is opened while it is in use?	7	17.5	25	62.5
5	Which of the following statements is true when using washing machine?	19	47.5	25	62.5
6	How often should air conditioner filters be replaced?	8	20.0	26	65.0
7	Which of the following is true about electric ovens?	25	62.5	38	95.0
8	What is the recommended temperature for water heating in dishwashers?	16	40.0	31	77.5
9	Approximately how many hours of electricity is consumed when the television set is left on standby mode at night?	6	15.0	30	75.0
10	Which of the following statements is not true about television sets?	17	42.5	27	67.5
11	Which of the following type of fans is more suitable for large rooms?	11	27.5	35	87.5
12	Which of the following is not true for notebook computers?	25	62.5	35	87.5
13	Which of the following definitions is correct for the term kilowatt-hour?	17	42.5	32	80.0
14	"Adjusting the brightness of televisions according to the room size can reduce its energy consumption." Is this statement true or false?	16	40.0	37	92.5
15	"Higher quality settings can increase the energy consumption of laser or inkjet printers." Is this statement true or false?	27	67.5	35	87.5
	Average:		**40.8**		**79.0**

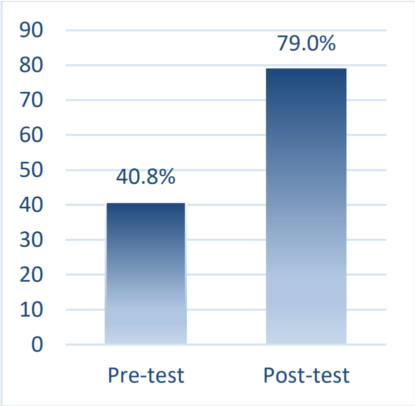

Figure 8 – Knowledge Gains

3.3 Key Challenges & Limitations of the Application of AR

The evaluation conducted revealed different limitations of the application of augmented reality for improving awareness on green consumption of electronic devices (RQ3). These are discussed as follows:

- *Need for customized markers*

ARGY makes use of the marker-based approach for identifying electronic devices. In this process, customized markers are needed in order to obtain correct energy related information. Without such markers, users would not be able to obtain energy information about appliances thus hindering the learning process. Alternatively, to reduce the dependency to markers, the marker-less based approach could be utilized. However, as discussed earlier, some limitations with this approach were found with large and shiny objects in addition to effects of light intensity (Vuforia Developer Portal, 2017).

- *More accurate energy estimates*

One of the key limitations of the application was that only an average energy estimate for each type of device is provided by ARGY. This was due to the various brands and models for each type of appliance that also have varying power requirements thus enormously increasing the number of specific markers that needed to be customized for large scale deployment of ARGY. Managing all the markers for the various types of appliances are also expected to be a challenging process. As a solution, since the application of the AR based approach showed positive knowledge gains amongst participant during the evaluation, manufacturers of appliances or even suppliers could integrate such markers in their devices thus providing energy related information using such approach in the future.

- *Need to activate/deactivate devices*

In order to obtain energy estimates, devices in use need to be activated using a toggle button during scanning mode as shown in Figure 4. Once the user has completed using the device, same needs to be deactivated in the application. This approach was found to best suit devices that need to remain powered for a long duration including refrigerator. However, for devices that need to be repeatedly switched on and off (e.g. television set or lights), this process becomes repetitive. As such, an automated approach for activating and deactivating the devices is needed and integration of other technologies such as nearfield communication (NFC) can improve usability (Ramrecha, et al., 2017).

- *Energy to Cost Translation*

In the implemented application, users were provided with energy consumption values in KWh and a group of participants was confused about this metric and could not understand its significance. Rather than KWh, integration of cost through relevant currency could better make users understand energy consumption and potential savings. As such, designers of such AR-based energy tools could target to show costs in addition to energy metrics.

- *Challenges in detecting markers*

The evaluation conducted revealed different challenges related to marker detection. First of all, participants owning smartphones having lower camera resolutions found it more challenging to detect markers with their mobile phones and this could impact adoption when deployed on a larger scale. Also, end users also reported to have faced challenges with marker detection under varying lighting conditions. This condition has also been experienced and investigated in different studies involving the application of augmented reality which also suggested the use of the sunglass effect to enhance visibility (Pasman, 1997; Azuma, et al., 1999; Gabbard, et al., 2006). Additionally, distance between the camera and marker was also found to impact marker detection as highlighted in some previous studies (Dorfmüller, 1999; Thomas, et al., 2000). Although varying marker sizes were customized, it was more challenging to detect markers at longer distances (e.g. lights and fans on ceilings).

- *Resource intensive*

Many participants also highlighted that utilizing the application was resource intensive such that it causes the mobile phone to heat up while also draining the battery. This was principally due to the use of the camera, which analyses images to identify the pre-defined targets in real-time mode. Some participants also mentioned about having to stop utilization of the application for some time before re-using. As such, in order to improve user experience when using AR to promote awareness on green consumption of electronic devices, lightweight libraries could be developed to process images in a more optimized manner.

- *Limitations of the study*

For answering the research questions, non-experimental research was conducted and as such, findings are based on interpretations, observations or interactions with the participants during the pre-utilization and post utilization sessions. Although measures were taken to ensure that participants used the system during one week, duration of use of the application among participants varied. Moreover, the one week was also highlighted to be relatively short by a small group of participants. Furthermore, the non-probabilistic sampling technique of convenience was adopted as sampling strategy and further evaluation could be conducted for assessing acceptance for general population.

4. CONCLUSIONS

This paper delved into the application of AR to improve awareness on green consumption of electronic devices by investigating 3 essential research questions. To be able to answer these questions, an AR-based mobile application named ARGY, was developed to help individuals learn energy consumption of electronic devices being used at home and offices. The application also provides a means for end users to track the amount of energy consumed by various devices, assess energy efficiency and provide appropriate tips and best practices to educate users on green practices. Following implementation of ARGY, a feasibility study was conducted to answer the key research questions pertaining to technological acceptance, knowledge gains and adoption barriers. For assessing technological acceptance, the Technology Acceptance Model (TAM) was utilized and for the evaluation of knowledge gains, pre-utilization and post-utilization tests were conducted involving 40 participants from Middlesex University (Mauritius Branch Campus). Following TAM assessment, results showed that on average, 55.0% of participants agreed or strongly agreed about the different criteria assessed under the 4 constructs, namely, perceived enjoyment, perceived ease of use, perceived usefulness and intention to use. Furthermore, in the post-utilization test, the average score for correct answers achieved by the participants increased to 79.0% as compared to 40.8% in the pre-utilization test thus showing a positive knowledge gain. This also shows that through the use of AR, participants were able to improve their awareness on green consumption of electronic appliances whereby highlighting the prospects of this technology towards promoting environmental sustainability. However, a few barriers and limitations to the implementation on a larger scale were also revealed, namely, the need for customized markers, need for more accurate energy estimates, challenges for detecting markers and resource intensity. These barriers could be further investigated by the research community in order to fully-exploit this prospective technology on a larger scale. Overall, the results revealed in this study highlight the prospects of AR for enhancing awareness on green consumption of electronic appliances and as such, manufacturers of electronic appliances could consider prospective application of this technology in their innovations.

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