

VISUALIZING ENERGY: AN AR APPROACH TO PROMOTING SUSTAINABLE CONSUMPTION HABITS

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Abstract— Energy consumption refers to the use of energy by household appliances, devices, and systems across residential, commercial, and industrial sectors. Beyond the total energy used, understanding consumption patterns is crucial in managing costs and promoting environmental sustainability. Many consumers lack awareness of how their daily energy usage impacts both expenses and the environment, leading to inefficient energy consumption, increased costs, and negative ecological consequences. This study explores the role of digital tools, particularly augmented reality (AR), in visualizing energy consumption and fostering sustainable habits. The research focuses on developing an AR-based Energy Consumption Awareness Application that provides users with interactive, real-time feedback on their energy usage. By leveraging a user-centered design approach and probability simple random sampling, this study evaluates how AR can enhance user engagement and encourage informed decision-making regarding energy efficiency. Results showed that 73.7% of participants were aware of appliance-level energy usage, 86.8% reported an increase in energy awareness after using the app, and 92.1% believed the app had the potential to influence their energy-efficient decisions. These findings support broader adoption of AR technology in energy management and present opportunities for collaboration with industry stakeholders such as Tenaga Nasional Berhad (TNB) or Suruhanjaya Tenaga.

Keywords—*Augmented Reality, Energy Awareness, Sustainable Behaviour, Marker-Based AR, Mobile Application, User Interface, 3D Visualization, Energy Consumption, Gamification, Unity3D*

I. INTRODUCTION

Energy consumption is steadily increasing worldwide, especially in developing nations like Malaysia, due to rapid urbanization and improved access to electricity [5]. In Malaysia, buildings account for a significant portion of electricity use, particularly for air conditioning and lighting [8]. Despite various public awareness campaigns, individuals often lack a concrete understanding of how their daily habits contribute to energy inefficiency.

Problem Motivation: A major challenge is the inability of consumers to access or interpret detailed appliance-level energy data. Electricity bills generally provide aggregate usage without actionable insights. This lack of transparency results in wasteful behavior and undermines efforts to promote energy conservation at the household level.

Research Gaps: Existing studies and applications often focus on total energy monitoring or use interfaces that are overly

technical, limiting accessibility and engagement [3]. Few studies have explored how Augmented Reality (AR) can be effectively leveraged to improve energy awareness in everyday contexts, particularly in Malaysian households. This study aims to fill that gap by developing and evaluating a user-friendly AR application that presents energy data in a compelling and interactive manner.

II. PROBLEM STATEMENTS

Many existing energy monitoring tools focus only on total consumption without providing detailed, appliance-specific insights, making it difficult for users to identify and change energy-wasting behaviors [3]. Additionally, the interfaces of many current energy application are often too technical or visually unappealing, which reduces user engagement and accessibility [2]. In Malaysia, limited public awareness on energy-efficient practices and a lack of innovative educational tools further worsen the issue [4]. To promote sustainable energy habits, there is a growing need for user-friendly and engaging tools. Augmented Reality (AR) shows potential in addressing these challenges by offering immersive, interactive ways to present energy usage information [1]. Without the adoption of such technologies, the shift towards energy-conscious behavior in Malaysian households may continue to be hindered.

III. RESEARCH OBJECTIVES

The advancement of this research aims to enhance public understanding, particularly among Malaysian household, about the importance of energy efficiency and the impact of individual appliance usage. The objectives of this study are:

- To identify the key design elements that enhance user engagement, usability, and comprehension in AR-based energy awareness application.
- To design and develop an interactive marker-based AR application that provides energy consumption feedback for household appliances.
- To evaluate the effectiveness of AR in educating users about energy efficiency, in contrast to conventional methods such as informational pamphlets or static visuals.

IV. LITERATURE REVIEW

A. Augmented Reality (AR)

Augmented Reality (AR) is a technology that enhance the real-world environment by overlaying digital elements such as images, sounds, and information onto physical surroundings. Unlike Virtual Reality (VR), which immerses users in entirely virtual spaces, AR integrates digital content into real-time views through devices like smartphones or AR glasses. This technology is widely used in areas such as education, gaming, and industry to create more interactive and immersive user experiences [6].

B. Energy Consumption in Malaysia

In Malaysia, electricity generation primarily depends on fossil fuels, with around 81.4% of energy production derived from natural gas and coal [7]. The growing demand for electricity is driven by urbanization, rising incomes, and increased usage of household appliances—especially air conditioning. To address environmental concerns and rising energy needs, Malaysia is pursuing renewable energy initiatives, such as the Malaysia Renewable Energy Roadmap (MyRER), which targets 20% renewable energy generation by 2025 [9]. Complementing this, the National Energy Efficiency Action Plan (NEEAP) promotes energy-saving practices through efficient technologies and consumer awareness [10]. Despite these efforts, the country still faces challenges in reducing its dependency on fossil fuels while ensuring energy security and sustainability.

C. Case Studies

To understand existing solutions in energy monitoring and the potential of Augmented Reality (AR) in this domain, several case studies were reviewed. These applications highlight key features, limitations, and areas for innovation that informed the development of the AR SparkView application.

- Smappee Energy Application – provides real-time appliance-level energy monitoring and smart home integration but requires costly hardware and technical setup.



Figure 1: Smappee Energy Application

- Emporia Energy Application – Affordable and offers real-time tracking but lacks AR features and focuses less on renewable energy integration.



Figure 2: Emporia Energy Application

- SmartThings by Samsung – Supports smart device automation with basic energy-saving functions but is not tailored for detailed energy tracking.

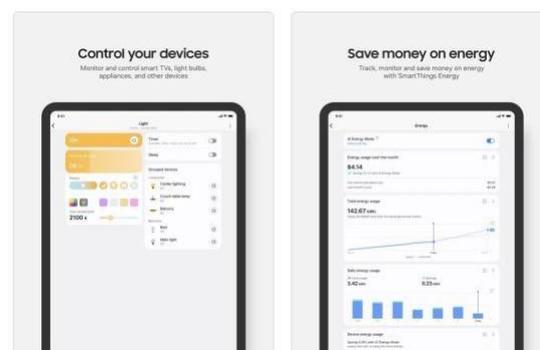


Figure 3: SmartThings by Samsung Application

- AR Platform at Energy Week @ ETH 2022 – Demonstrated AR’s potential for visualizing energy concepts in exhibitions, though It lacks personal tracking features for everyday use.



Figure 4: AR Platform at Energy Week @ ETH 2022

V. RESEARCH METHODOLOGY

The AGILE methodology was adopted for this project due to its iterative and flexible nature, allowing for continuous feedback and development. The research employed a **quantitative design**, focusing on measuring user responses to the AR application using a structured survey instrument.



Figure 5: AGILE Model

A. Plan (Research Design and Scope)

This initial phase involved identifying project goals, defining the scope, and conducting background research on existing energy awareness tools. The research adopted a quantitative approach to measure the impact of the AR application through pre-defined metrics such as user awareness, satisfaction, and behavioral change. A user-centered design principle guided the development process.

B. Design (System and Instrument Design)

A low-fidelity storyboard was created using Procreate, and later translated into interactive wireframes using Figma to define the layout and user journey. The prototype was designed to simulate appliance-level energy consumption feedback in a mobile AR environment. Survey instruments were designed in parallel to evaluate usability and awareness outcomes.

C. Develop (Tool Utilization and Feature Implementation)

The application was developed using the Unity3D engine, integrating Vuforia SDK for marker-based AR functionality. Blender was used to model the 3D appliances, ensuring visual accuracy and performance optimization for mobile deployment. The energy calculation system and interactive “tree growth” reward mechanism were programmed in C#.

D. Test (Data Collection and Sampling)

A structured questionnaire was used to evaluate the prototype. Data were collected from 38 participants selected using simple random sampling. Participants included university students and early-career professionals aged between 20–35 years. Each participant interacted with the app in a supervised session lasting approximately 20 minutes and completed a post-intervention survey immediately after. The survey included Likert-scale items focused on usability, learning impact, and decision-making changes.

E. Deploy & Review (Evaluation and Refinement)

In the final phase, the application was deployed for user testing, followed by a comprehensive review based on participant feedback and evaluation data. A post-usage questionnaire was administered to assess the effectiveness of the application in promoting energy awareness and influencing behavioral change.

The findings revealed that 73.7% of participants demonstrated awareness of appliance-level energy usage, while 86.8% reported an increase in overall energy usage awareness after interacting with the application. Notably, 92.1% of respondents agreed that the application has strong potential to influence their decisions towards more energy-efficient behaviors.

Based on the feedback, several refinements were implemented. These included:

- Enhancing the user interface for better clarity and engagement,
- Improving the visual fidelity and realism of the 3D appliance models,
- Increasing the responsiveness of AR interactions,
- Optimizing performance for smoother real-time operation on mobile devices.

These improvements contributed to a more polished, user-friendly experience, reinforcing the application's goal of encouraging sustainable consumption habits through immersive AR visualization.

E. Tools and Software

The application was developed using Unity3D with the Vuforia SDK for AR functionality. Blender was used for 3D modeling of appliances. Figma and Procreate were utilized for UI wireframing and storyboard design. Data from surveys were analyzed using Microsoft Excel **and** SPSS for basic descriptive statistics.

VI. PROJECT DEVELOPMENT AND DESIGN

This section presents the development process and design approach for the AR SparkView application. It covers the media specifications, interface design, content structure, and system configuration. Key design decisions made during prototyping—such as layout, media choices, and interactivity—are also discussed. The development was guided by user-centered design principles and the Agile methodology to create a functional and engaging AR application that promotes energy awareness.

A. Flowchart

The developer started with an application navigation structure to ensure clarity, ease of use, and intuitive navigation.

Figure 6 illustrates the overall navigation structure of the SparkView AR application, outlining how users move between key interfaces. The design includes intuitive pathways connecting the Home screen, AR Camera, Energy Usage Panels, and the Tree Growth reward section. This structured flow ensures a smooth user experience by minimizing complexity and guiding users through each feature with clarity and ease.

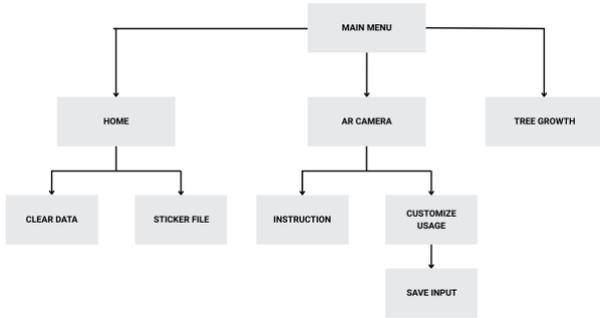


Figure 6: Application's navigation structure

B. Storyboard

The storyboard was produced throughout the design phase to visualize key user interactions and interface screens. This allowed for quick iteration of ideas and creative freedom during the early concept phase.

Figure 7 presents the storyboard used during the design phase of the SparkView AR application. This storyboard served as a visual planning tool to map out the user journey and interface interactions before actual development began. It outlines the sequence of screens a user would encounter—from launching the app and accessing the AR camera to viewing appliance data and engaging with the tree growth feedback system.

Each frame in the storyboard represents a specific user action or system response, helping the design team visualize the overall flow, layout, and functionality. This approach allowed for early validation of concepts, efficient iteration, and alignment with user-centered design principles. By using tools like Procreate for sketching and Figma for digital refinement, the team ensured that the final application would offer a logical and engaging

experience for users.

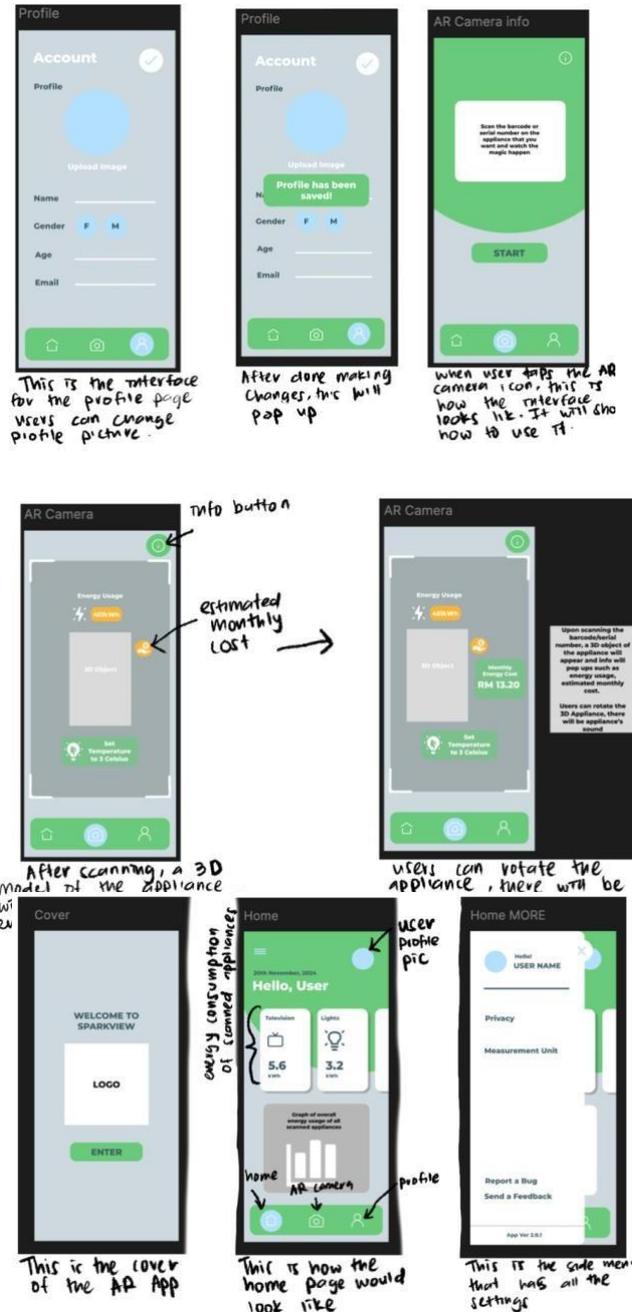


Figure 7: Storyboard

C. Typography

The fonts chosen creates a professional and accessible look that supports both clarity and brand consistency throughout the application.

Figure 8 highlights the typography choices used throughout the SparkView AR application interface. Typography plays a crucial role in enhancing readability, user engagement, and the overall aesthetic of the application. The selected fonts were chosen for their clarity, consistency, and suitability across different screen sizes on mobile devices.

The primary typeface provides a clean, modern look that aligns with the app's professional and educational tone. It is used for key interface elements such as navigation menus, labels, and content descriptions. A secondary font style is applied selectively to emphasize headings, interactive buttons, and energy data readings, creating a clear visual hierarchy that guides the user's attention.

These typography decisions support accessibility by ensuring that text remains legible in various lighting conditions and across different user devices. The consistent font usage also contributes to brand coherence and user interface (UI) simplicity, both of which are essential for delivering a seamless and intuitive user experience.



Figure 8: Typography

D. 3D Appliance Models

These 3D assets were optimized for mobile AR performance and imported to Unity for interaction. Each model is visually accurate to its real-world counterpart to enhance user recognition and immersion.

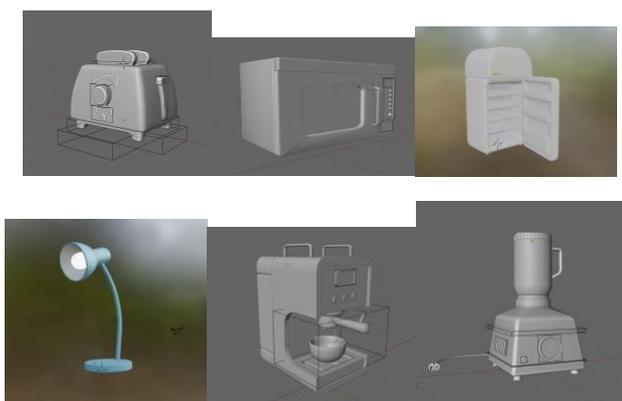


Figure 9: 3D Appliance Models

VII. RESULT AND TESTING

This section presents the result gathered from the user testing and evaluation of the SparkView AR application, followed by an in-depth discussion of the findings relation to the research objectives.

Figure 10 presents the participants' existing awareness of energy consumption at the appliance level before using the application. The results show that 73.7% of users were already somewhat aware of which appliances consume more energy. This indicates a moderate baseline awareness, which provided a foundation for measuring the app's impact.

Are you currently aware of how much energy your household appliance consume?
 38 responses

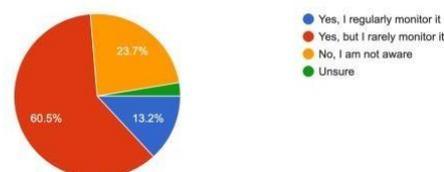


Figure 10: Awareness of Appliance Energy Usage

After interacting with the SparkView AR application, 86.8% of users reported an increased understanding of their energy consumption behavior as in Figure 11. The visual, interactive AR elements significantly enhanced their ability to recognize energy-intensive appliances and relate usage to cost and sustainability. This result demonstrates the effectiveness of AR in making abstract energy data more tangible and engaging.

15. I feel more aware of my energy usage after using this application.
 38 responses



Figure 11: Increase in Energy Usage Awareness after using App

92.1% of participants stated that the application influenced their intention to adopt energy-efficient practices as in Figure 12. This strong response highlights how AR-based tools like SparkView can effectively drive behavioral change and support the study's goal of promoting sustainable energy habits through technology.

16. The feedback provided could help me make more energy-efficient decisions.
 38 responses

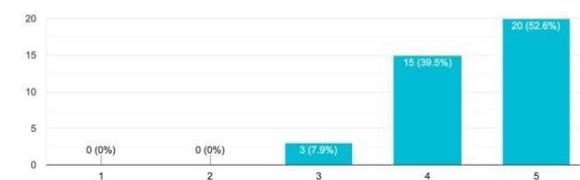


Figure 12: App's Potential to Influence Energy-Efficient Decisions

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