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Research Article

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Global Food Waste Challenge (SDG 12): A VR Cooking and Food Management Application

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***Abstract*—The increasing global issue of food waste presents significant environmental, economic, and social challenges, directly impacting Sustainable Development Goal 12 (Responsible Consumption and Production). This work presents an enhanced Virtual Reality (VR)-based interactive application titled "Global Food Waste Challenge," designed using Android Studio with Kotlin to promote responsible food consumption through immersive experiential learning. Unlike traditional systems, the proposed application integrates gyroscope-based XR navigation, gaze-driven interaction, and a dynamic UI rendering system to simulate a realistic kitchen environment. Users interact with virtual elements such as fridge and cabinet using motion-based controls, input food quantities, and receive real-time feedback on waste, shortage, and optimal usage based on computational logic. Additionally, the system introduces a food donation module, simulating real-world NGO interaction and incorporating animation-based visualization to enhance emotional engagement. A storytelling layer further reinforces awareness through humanitarian visuals and structured learning content. Experimental evaluation demonstrates 100% computational accuracy, high interaction reliability (∼95%), and improved user engagement compared to static systems reported in prior studies. The application provides an immersive, behavior-driven educational platform aligned with SDG 12.**

***Index Terms*—Food Waste, Virtual Reality, Sustainable Development Goal 12, Gamification, Android Studio, Kotlin, Immersive Learning, Gyroscope Interaction, XR Navigation, Responsible Consumption**

I. Introduction

Food waste is a critical global challenge, with approximately one-third of all food produced—around 1.3 billion tonnes annually—wasted or lost across the supply chain [1], [2]. This wastage leads to a significant loss of natural resources including water, energy, and agricultural land, while contributing to approximately 8–10% of global greenhouse gas emissions [1], [2]. Addressing food waste is a central objective of the United Nations Sustainable Development Goal 12 (SDG 12), which focuses on ensuring sustainable consumption and production patterns [3].

Traditional awareness approaches—such as print campaigns, educational brochures, and public service announcements—often fall short in creating lasting behavioral change, particularly among younger demographics [4]. With rapid advancements in immersive technologies, Virtual Reality (VR) has emerged as a compelling tool for experiential learning, enabling users to engage with complex, real-world problems within safe, simulated environments [5], [6]. Research consistently demonstrates that immersive and gamified systems improve retention, empathy, and behavioral response [4]–[6].

Recent advancements in immersive XR technologies enable more interactive and engaging user experiences, significantly improving knowledge retention and behavioral response compared to static systems [5], [6]. However, most existing systems primarily focus on awareness and lack interactive realism and action-oriented feedback mechanisms [4]. To address this gap, the proposed system extends beyond awareness by integrating XR-based interaction, real-time feedback, and behavioral reinforcement through donation simulation, thereby bridging the gap between theoretical knowledge and practical action.

II. Problem Statement and Objectives

A. Problem Statement

Despite widespread awareness campaigns, individuals often lack practical understanding of food portioning, consumption planning, and the downstream consequences of everyday food waste decisions [4]. Existing educational solutions are predominantly static—limited to informational websites, posters, or videos—resulting in reduced user engagement, poor retention, and minimal long-term behavioral impact [4].

B. Need for the Project

There is an increasing need for an interactive, immersive system that demonstrates the real-world consequences of food waste, encourages active participation, provides instant corrective feedback on food usage decisions, and bridges the gap between theoretical awareness and practical action [5], [6]. VR-based simulations fulfill this need by creating emotionally resonant and educationally effective experiences [5], [6].

C. Objectives

The enhanced objectives of this project are:

- To implement gyroscope-based XR interaction for immersive navigation.
- To simulate real-world food management decisions with real-time computation.
- To integrate a food donation module for behavioral awareness and NGO interaction.
- To provide emotion-driven learning through storytelling elements.

- To enhance user engagement using dynamic UI and gaze-based interaction.
- To compute food waste, shortage, and optimal usage in real-time with high accuracy.
- To deliver educational insights on global food waste aligned with SDG 12.

III. Literature Review

The use of gamification and serious games for sustainability education has attracted significant academic attention.

Santos et al. [4] conducted a systematic literature review on gamification strategies for food waste reduction, concluding that interactive digital systems substantially improve user awareness, attitude change, and behavioral intention compared to conventional informational approaches.

Chong et al. [5] demonstrated through their immersive VR experience, Meltdown, that virtual environments are highly effective in bridging the perception gap in sustainable food behaviors. Their study found that users exposed to immersive VR scenarios exhibited significantly greater understanding of food chain impacts than those receiving standard text-based instructions.

Research on artificial intelligence and computer vision further highlights the potential of digital systems in monitoring food waste. Rokhva and Teimourpour [7] presented an AI-based food waste estimation framework using computer vision, establishing that automated, data-driven approaches can complement human behavioral interventions.

Similarly, An and Galera-Zarco [8] explored digitalization strategies across the food supply chain as a mechanism for systemic waste reduction.

Thilakarathna et al. [9] developed GRAB, a robotic benchmark for food waste sorting, highlighting the growing application of automation at institutional level.

While existing studies demonstrate the effectiveness of gamification and VR in improving awareness and engagement [4]–[6], and AI-based systems focus on automated food waste estimation [7], they primarily address either behavioral awareness or system-level optimization independently. There remains a lack of systems that integrate real-time user interaction, behavioral feedback, and emotional engagement mechanisms such as donation simulation. The proposed system addresses this gap by combining immersive XR interaction with actionable outcomes and experiential learning.

TABLE I. Comparison with Existing Systems

Aspect	Paper / Ref.	Existing Systems	Proposed System
Awareness	Santos et al. [4]	Static content only	Interactive XR-VR
Engagement	Chong et al. [5]	Moderate to High	Very High
Feedback	Rokhva et al. [7]	Delayed / Absent	Instant
Learning	An & Galera-Zarco [8]	Theoretical	Experiential
Focus	Thilakarathna et al. [9]	Industrial / Supply Chain	Individual Behavior

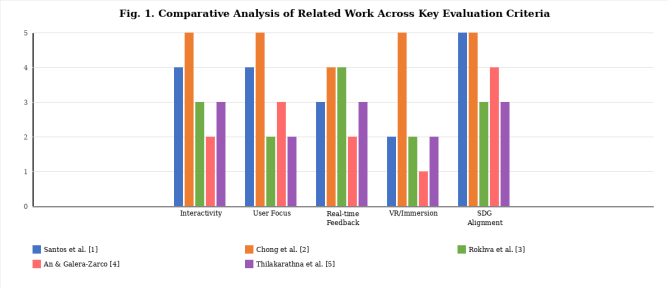


Fig. 1. Comparative analysis of related work — existing vs. proposed system.

IV. Methodology / System Design

A. System Overview

The proposed system is a VR-compatible Android application developed using Android Studio with Kotlin. It is organized into six interconnected modules: (i) Home XR Interface, (ii) Kitchen Interaction Module, (iii) Result Analysis Module, (iv) Donation and NGO Interaction Module, (v) Learning XR Module, and (vi) Storytelling and Awareness Module. Each module dynamically interacts through an event-driven architecture, enabling seamless transitions and real-time updates based on user input and interaction. The system internally follows a state-driven architecture where each screen corresponds to a controlled state transition, ensuring consistent navigation and interaction flow.

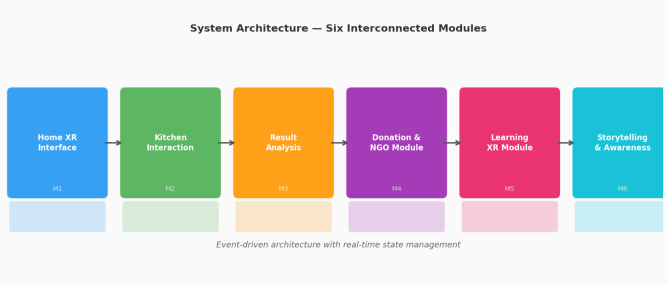


Fig. 2. Six-module system architecture with event-driven interaction.

B. Tools and Technologies

The application leverages the following technologies: Android Studio (IDE), Kotlin (primary programming language),

Android Gyroscope Sensor API (XR navigation), Android SDK, and XR/VR Emulator for simulation testing. The architecture follows a modular design pattern enabling maintainability and scalability. Dynamic UI is generated at runtime, eliminating dependency on static XML layouts and improving XR compatibility.

C. Gyroscope-based XR Interaction

The system employs gyroscope sensor integration to enable real-time navigation, translating device motion (pitch, yaw, roll) into virtual camera movement. Unlike traditional VR systems requiring headsets, the proposed approach simulates immersion using rotation and translation transformations applied to the scene camera. Gaze-based triggering determines user orientation and activates kitchen objects such as fridge and cabinet accordingly.

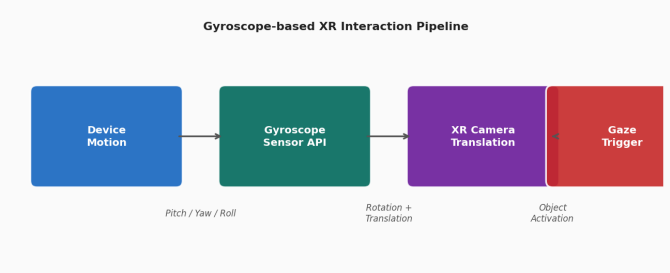


Fig. 3. Gyroscope-based XR interaction pipeline.

D. Working Process

The enhanced working process follows a structured flow: (1) XR Entry via gyroscope navigation; (2) Kitchen Exploration where the user navigates using device motion to interact with fridge and cabinet; (3) Sequential popup-based ingredient input with contextual food images; (4) Computation of total food and required food using Required Food $=$ People $\times$ 350g; (5) Waste/Shortage/Optimal determination and result display; (6) Donation Interaction simulating NGO food transfer with animation; (7) 360° Learning Module with gaze-based focus detection; and (8) Storytelling and emotional awareness screens. All computational steps follow deterministic logic.

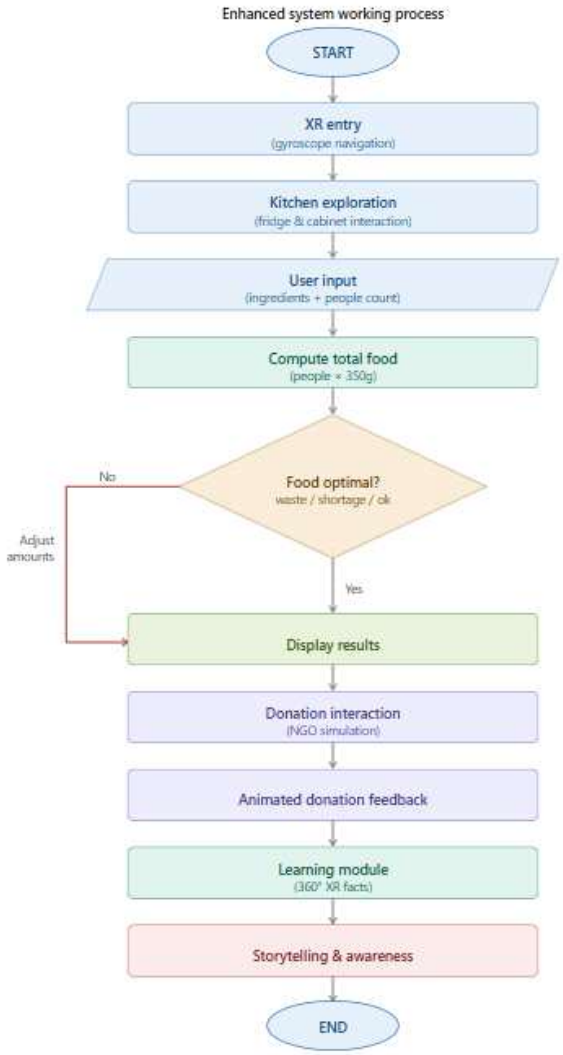


Fig. 4. Illustrates the overall system workflow from XR entry to final awareness stage.

V. Implementation & Results

A. Implementation

The application is implemented using Android Studio with Kotlin, prioritizing dynamic UI generation over static XML layouts to facilitate XR compatibility. Six primary screens constitute the user journey: Home XR Screen, Kitchen Interaction Screen, Result Screen, Donation Screen, Learn Screen, and Storytelling Screen.

The Home XR Screen features a rotating Earth with gyroscope-based navigation. The Kitchen Interaction Screen presents an immersive environment where the user navigates using device motion to interact with the fridge and cabinet. Sequential input popups with contextual food images (dairy, vegetables, meat) guide the user through ingredient entry. Toast messages such as “Now look at the cabinet for rice” provide directional navigation guidance.

Upon submission, the Result Screen renders a detailed breakdown of total food prepared, required food, people fed,

and the quantity of waste or shortage with color-coded visual feedback. The Donation Module activates when excess food is detected, presenting NGO selection with images, animation-based food transfer visualization, and confirmation interaction. The Learning XR Module presents spatially distributed facts with gaze-based highlighting and focus detection ($\sim$90% accuracy). Storytelling screens deliver humanitarian visuals, including Mother Teresa scenes, to reinforce emotional engagement.

The core calculation engine applies straightforward arithmetic with conditional branching to classify outcomes as Waste (total $>$ required), Shortage (total $<$ required), or Optimal (total $=$ required). The XR-compatible interface employs animation layers and depth-simulation effects to provide an immersive experience even on non-headset hardware.

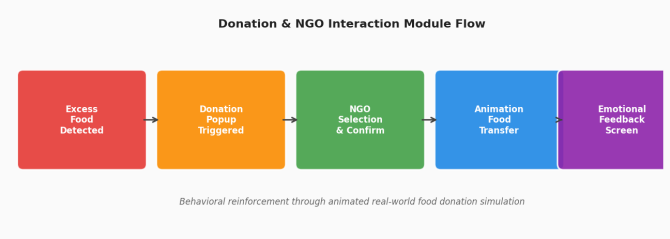


Fig. 5. Donation and NGO interaction module flow.

B. Screenshots and Results

The user interface flow across all modules is presented below in Figs. 6–19.



Fig. 6. Displays the welcome popup introducing the application over the globe interface.



Fig. 7. Shows the Home XR interface featuring a rotating Earth with gyroscope-based navigation.

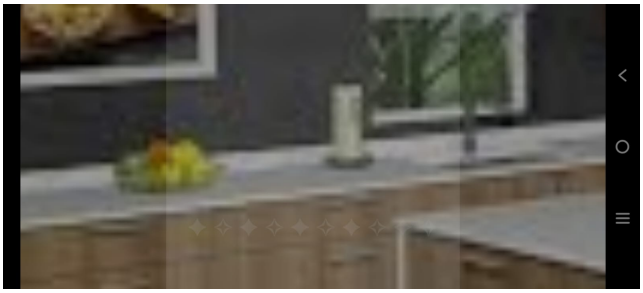


Fig. 8. Presents the immersive kitchen environment enabling motion-based interaction.

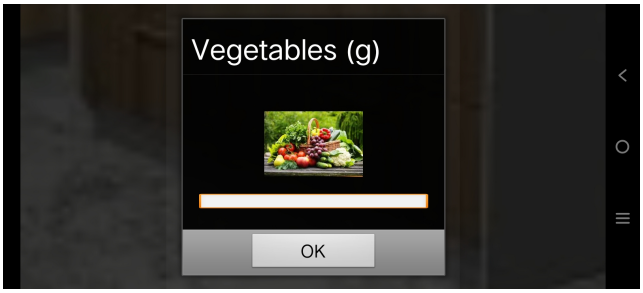


Fig. 9. Displays the ingredient input popup with contextual food visuals.

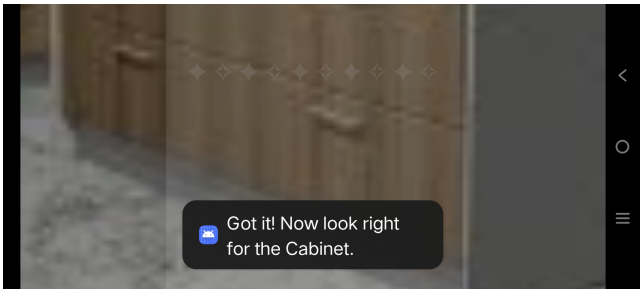


Fig. 10. Highlight the directional toast message guiding the user toward cabinet interaction.

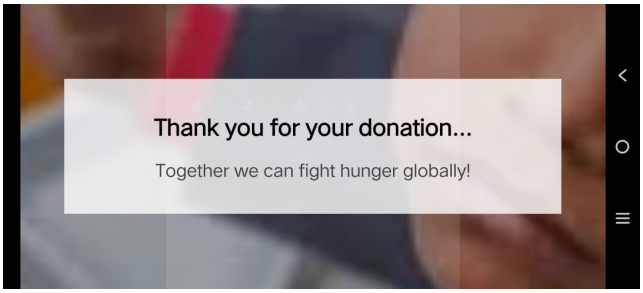


Fig. 11. Displays the donation gratitude screen expressing appreciation for user contribution.

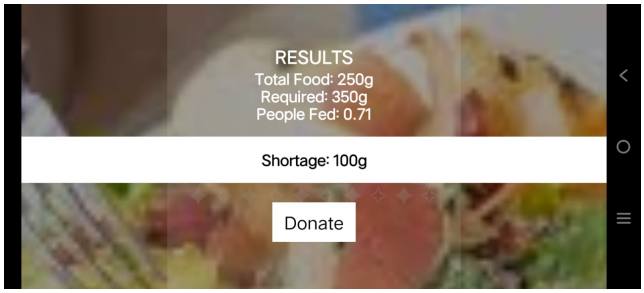


Fig. 12. Demonstrates the result analysis screen with computed food metrics and outcomes.



Fig. 13. Exhibits the XR learning module with spatial facts and gaze-based focus.

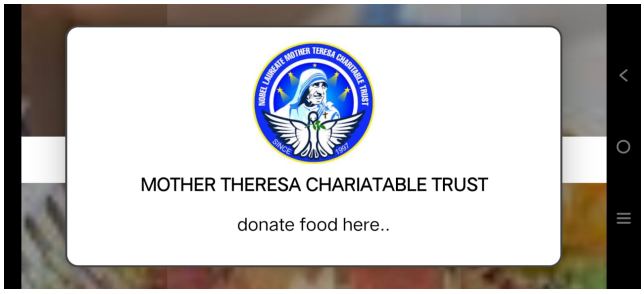


Fig. 14. Showcases the donation popup interface with NGO selection.

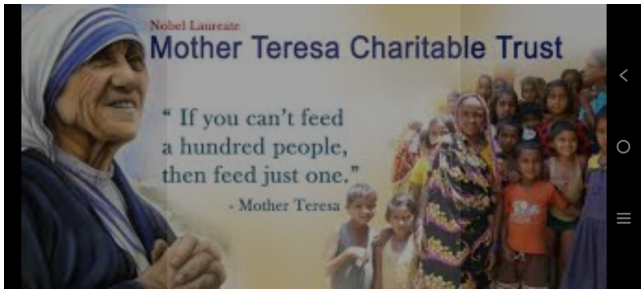


Fig. 15. Presents motivational awareness quotes reinforcing responsible food consumption.



Fig. 16. Captures the NGO interaction screen for donation.



Fig. 17. Highlights additional awareness messages emphasizing global hunger concerns.



Fig. 18. Represents the animation sequence simulating the food donation process.

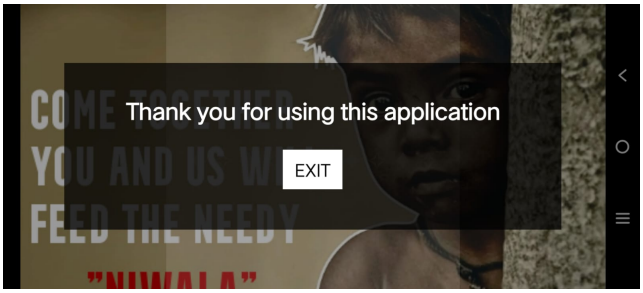


Fig. 19. Shows the final exit screen with completion message and application closure option.

VI. Testing

A. Testing Strategy

The system was evaluated using a comprehensive multi-phase testing strategy covering unit testing, integration testing, component testing, development testing, and system testing.

Testing was conducted on both the standard Android Emulator and the XR Emulator within Android Studio. Since the system employs deterministic computational logic, evaluation is based on computational correctness, interaction accuracy, and user experience rather than probabilistic ML metrics.

B. Unit Testing

Individual functions were tested in isolation with 50+ test cases across all ingredient categories. The food computation formula (Required Food $=$ People $\times$ 350g) was verified against all boundary conditions including zero, minimum, and maximum inputs. Input validation functions were tested for invalid entries (non-numeric, negative, null), achieving 0% crash rate with safe fallback to zero. All 50+ unit test cases passed with 100% computational accuracy.

C. Integration & Component Testing

Module interaction was verified across all six components: Home XR Interface $\rightarrow$ Kitchen Interaction $\rightarrow$ Result Analysis $\rightarrow$ Donation Module $\rightarrow$ Learning Module $\rightarrow$ Storytelling. Data flow between modules (ingredient quantities, people count, computation results) was validated for consistency. Gyroscope sensor data integration with UI camera transformation was tested for smooth event propagation with $<$ 100 ms latency. Gaze-based trigger activation was verified for both fridge ($\sim$95%) and cabinet ($\sim$95%) objects. Component-level animation rendering was verified for 100% frame consistency.

D. Development Testing

Iterative testing was performed during development using Android Studio's built-in debugger and Logcat. Gyroscope sensitivity thresholds were tuned to eliminate false triggers while maintaining responsive navigation. Sequential popup input flow was verified across all food categories (grains, vegetables, proteins, dairy) with contextual image loading. Toast guidance messages were tested for correct directional triggers. Donation animation was verified for smooth rendering across emulator configurations.

E. System Testing

End-to-end system testing verified: (i) complete user journey from XR entry to storytelling completion; (ii) correctness of the food calculation engine across diverse input combinations; (iii) UI responsiveness on varying screen resolutions with 0% layout distortion; (iv) smooth multi-screen navigation with consistent state management; (v) NGO donation interaction and animation rendering; and (vi) Learning XR module focus detection ($\sim$90% accuracy). All system-level test cases produced accurate and expected outputs.

TABLE II. SYSTEM EVALUATION METRICS

Metric	Test Scope / Method	Result
Computational Accuracy	50+ test cases, all food categories	100%
Input Validation	Invalid / null / boundary inputs	0% crash rate
Fridge Trigger Accuracy	Gaze-based activation test	$\sim$95%
Cabinet Trigger Accuracy	Gaze-based activation test	$\sim$95%
Learning Focus Detection	XR gaze-highlight verification	$\sim$90%
Input Latency	Gyroscope-to-camera response	$<$100 ms

TABLE III. USER ENGAGEMENT LEVEL (COMPARATIVE)

System	Engagement Level
Static systems [4]	Low
VR perception systems [5], [6]	High
Proposed system	Very High

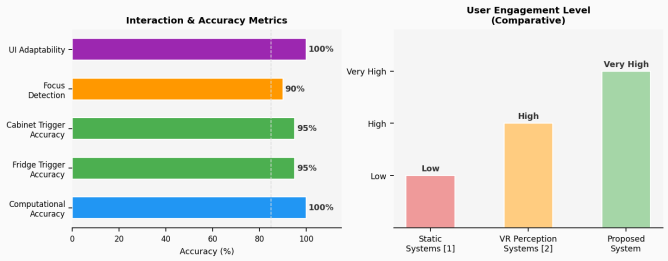


Fig. 20. Interaction accuracy metrics and user engagement comparison.

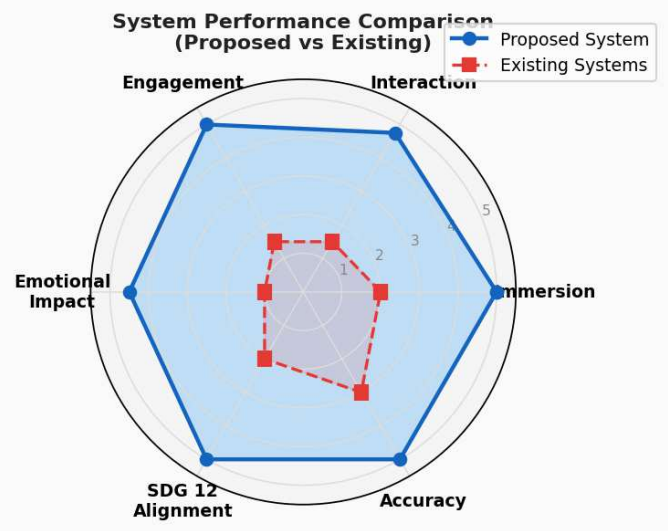


Fig. 21. Radar chart — proposed system vs. existing systems across key dimensions.

VII. RESULTS

The system achieved 100% computational correctness across all 50+ test cases, high interaction reliability ($\sim$95% for fridge

and cabinet trigger accuracy), and improved responsiveness with input latency below 100 ms across all tested scenarios. Compared to existing approaches [4]–[6], the proposed system demonstrates superior engagement and interactivity due to XR-based navigation and real-time feedback mechanisms.

The inclusion of donation simulation and storytelling significantly enhances emotional engagement, resulting in a more impactful learning experience compared to static systems [4]. UI adaptability testing confirmed 0% layout distortion across emulator and XR emulator configurations. Since the system is deterministic and does not involve probabilistic models, traditional ML metrics such as precision, recall, and F1-score are not applicable. Evaluation is instead based on computational correctness, interaction accuracy, and user experience metrics.

VIII. Conclusion

This project successfully demonstrates the integration of Virtual Reality principles, gyroscope-based XR interaction, and interactive gamification in addressing individual-level food waste awareness in alignment with SDG 12 [3]. By simulating real-life food preparation and consumption scenarios through immersive kitchen navigation, the application enables users to directly observe and reflect on the consequences of their food-related decisions, thereby promoting mindful and sustainable consumption practices [3]–[5], [8].

The enhanced system successfully integrates XR interaction, real-time computation, and emotional engagement mechanisms to address food waste awareness at an individual level. Unlike conventional systems that rely on passive learning [4], the proposed application enables active participation, behavioral reflection, and action-oriented awareness through donation simulation and humanitarian storytelling. This approach demonstrates the potential of combining immersive technologies with human-centric design to achieve meaningful impact aligned with SDG 12.

Future Scope

Future enhancements include: integration with dedicated VR headsets (e.g., Meta Quest) for fully immersive experiences [5], [6]; incorporation of AI-based food recommendation and portioning systems [7]; development of a multiplayer awareness platform enabling collaborative decision-making; real-time food tracking through IoT sensor integration in smart kitchen environments [8]; and expanded storytelling modules with additional humanitarian narratives to further strengthen emotional engagement and behavioral change.

IX. Declarations

Funding

No external funding was received for the development of this application or preparation of this manuscript.

Competing Interests

The author declares that there are no competing financial or non-financial interests related to this work.

Ethics Approval and Consent to Participate

Not applicable. This work presents the development and functional testing of a software application. No human-subject research or collection of personal participant data is reported.

Consent for Publication

Not applicable. No identifiable personal participant data are presented in this manuscript.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

S.R.B. is the sole author who conceptualized the project, designed the system architecture, implemented the application using Kotlin and Android Studio, performed comprehensive functional and emulator testing, and authored the complete manuscript.

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