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Research article

Sustainable Technology: Development of a Multi-functional Device using Recycled E-Waste Components

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A B S T R A C T

The study explores the innovative creation of a household multi-functional device (MFD) by repurposing e-waste components. This MFD prototype integrates the functions of a rice cooker, LCD TV, DVD player, amplifier, and electric fan, utilizing both AC and DC power, with alternative energy inputs from solar panels, hand-cranked generators, and rechargeable batteries. Through a structured development approach involving design, procurement, repair, and testing stages, the study demonstrates how e-waste can be effectively transformed into valuable, multifunctional household technology, thereby reducing environmental impacts.

This research also evaluates the MFD's acceptability based on functionality, economy, maintainability, and safety, as assessed by different experts in the field. All groups rated the device highly, confirming its utility (with an overall functionality mean score of 3.79 out of 4), cost-effectiveness (with an overall mean of 3.89 out of 4), maintainability (with an overall mean score of 3.81 out of 4), and safety in diverse conditions, especially during power outages (with an overall mean score of 3.87 out of 4). Statistical analyses indicate no significant differences in assessment scores across respondent groups, underscoring the device's broad appeal. This research provides a model for addressing e-waste through creative reuse, offering environmental benefits and potential market applications.

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1. INTRODUCTION

In contemporary society, computers have become essential across numerous fields. Since their inception, computer technology has advanced rapidly. Early computers, which once required an entire room, have evolved into devices small enough to fit in a pocket. This ongoing innovation in electronics has led to frequent obsolescence, as each new model replaces its predecessor at an increasingly rapid pace.

Over the past two decades, the global market for electrical and electronic equipment has grown exponentially. However, the lifespan of these devices has shortened considerably, with obsolescence now occurring at a concerning rate. The primary issue associated with this trend is the disposal of outdated devices, commonly known as electronic waste, or e-waste.

E-waste refers to obsolete, broken, electronic devices like tv, cpu, computer monitors, laptops, printers, scanners, and wiring. E-waste has become a concern due to the high volumes in which it is generated, the hazardous constituents it often contains (such as lead, mercury, and chromium), and lack of regulations applicable to its disposal or recycling [1-2].

The electronic industry is the world's largest and fastest growing manufacturing industry [3-4]. Electronic waste (e-waste) comprises waste electronics/electrical goods that use or have reached their end of life. Electronic waste, or e-waste, includes white goods, consumer and business electronics, and information technology hardware that has reached the end of its useful life [5]. A more detailed definition describes e-waste as "a broad and growing range of electronic devices, including large household appliances such as refrigerators and air conditioners, as well as cell phones, personal stereos, consumer electronics, and computers that have been discarded by their users" [6]. In essence, e-waste refers to any electronic device that is no longer usable for its owner, whether due to being broken, outdated, or simply replaced by preference, and electronic wastes can cause severe environmental damage due to the use of toxic materials in the manufacture of electronic goods [7].

Today, waste electrical and electronic equipment (WEEE) or electronic waste (e-waste) generation, trans-boundary movement and disposal are becoming issues of concern to solid waste management professionals, environmentalists, international agencies and governments around the world [8]. The useful life of consumer electronic products is relatively short, and decreasing as a result of rapid changes in equipment features and capabilities [9].

Generally, e-waste may be addressed in only a limited number of methods, recycling and refurbishing. Currently, recycling of e-waste can be broadly divided into three major steps, namely, disassembly, upgrading, and refining.

In the Philippines, the rapid disposal of electronic and electrical items mirrors global trends and continues to increase. This pattern suggests that the country faces similar challenges in managing e-waste. Consequently, the Philippines is likely to encounter growing difficulties with e-waste disposal. Current waste management practices, including reuse and recycling, are also employed in the Philippines.

Given the country's substantial e-waste production, its evolving technological landscape, and the limited e-waste reduction methods that primarily rely on reuse and recycling, the researcher explored an alternative approach to reducing e-waste. Building on the principles of reuse and recycling, this approach combines reusing, refurbishing, repairing, and recycling with added innovation and creativity. The researcher integrated these concepts to develop a solution aimed at minimizing the volume of e-waste in the country. This solution involves creating a multifunctional device using e-waste materials acquired through reuse, refurbishment, and repair, with irreparable components replaced as needed. This study was therefore conducted to complete and realize this innovative approach to e-waste reduction.

2. METHODOLOGY

This section presents and discusses the different methods used in the development of a multi-functional device (MFD) from recycled e-waste.

2.1 Research Design

This study adopted an innovative development approach to realize the prototype. As illustrated in Figure 1, this study utilized a waterfall model, a structured process in which each stage must be completed before advancing to the next.

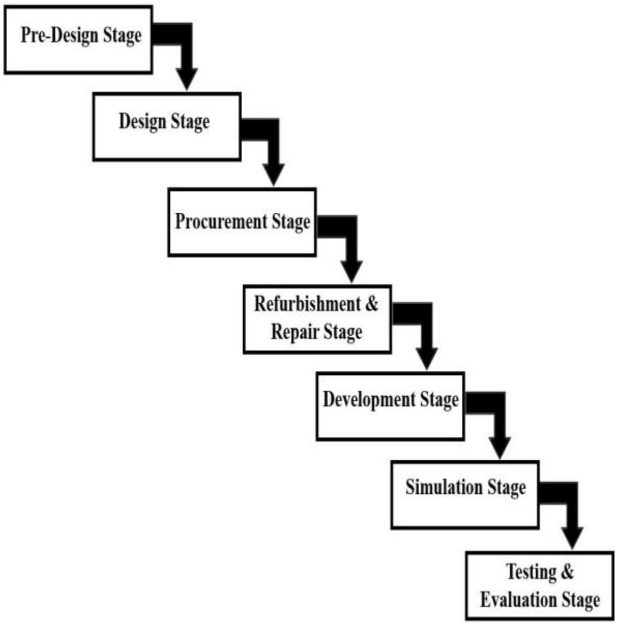

Fig. 1. Research Design Process.

A descriptive approach was employed to evaluate the prototype. The descriptive method involves exploring and detailing phenomena in real-life situations, providing an accurate account of the characteristics of specific individuals and the meanings behind them. This method entails a purposive process of data gathering, analyzing, classifying, and tabulating information regarding prevailing conditions, practices, beliefs, process trends, and cause-effect relationships. It culminates in the adequate and accurate interpretation of this data, with or without the use of statistical treatment.

2.2 Data Gathering

To assess the performance of the prototype, the researchers utilized a multi-tester to measure electrical values, including voltage, amperage, and wattage. These values were recorded in a data sheet format for subsequent statistical analysis.

Additionally, a self-structured survey questionnaire was employed to collect data on the prototype's functionality, maintenance, economy, and safety. Each category was evaluated using a Likert scale. The questionnaire underwent a validation process, after which the validated surveys were distributed to respondents during the testing and evaluation phase.

2.3 Data Analysis

The collected data were analyzed using both descriptive and inferential statistical tools. Specifically, the analysis involved frequency distribution, percentages, ranking, mean, variance, standard deviation, composite mean, and analysis of variance (ANOVA).

2.4 Frequency Distribution and Percentage

Frequency distribution and percentages are crucial in data analysis as they organize and summarize data, allowing researchers to quickly identify patterns, trends, and outliers. They facilitate visual representation through tables or graphs, enhancing comprehension and communication of findings. Percentages express the relative frequency of responses, providing insights into the significance of data points, which aids in decision-making. Additionally, frequency distributions serve as a foundation for more advanced statistical analyses and enable comparative analysis between different groups or categories. Overall, these tools help researchers interpret and communicate empirical evidence effectively.

Relative Frequency. This analysis was employed to display the relative frequency of survey responses for each evaluation category.

Ranking. This method was utilized to identify the highest-rated item within each category and to determine the category in which the prototype received the highest overall rating.

Mean. The mean was calculated to ascertain the central tendencies of the output values from the prototype's modules. It was also used to evaluate the central tendencies of respondents' ratings for each item across all categories.

To interpret the mean, the following ranges and verbal descriptions were used:

3.45 - 4.00	Excellent (E)
2.45 - 3.44	Very Good (VG)
1.45 - 2.44	Good (G)
1.00 - 1.44	Fair (F)

Variance. This metric served as a prerequisite for calculating the standard deviation of the output values from the prototype's modules.
Standard Deviation. This statistic was used to identify the minimum and maximum ranges of the output values for the prototype's modules.

Composite Mean. The composite mean was calculated to assess the evaluation of the prototype in each category, as well as to determine the overall evaluation.

Analysis of Variance (ANOVA). This method was employed to assess whether significant differences existed in the evaluations provided by the three groups of respondents.

3. RESULTS AND DISCUSSION

This section shows the results of the study, their analyses and interpretation of gathered data regarding the multi-functional device from the recycled e-waste materials.

3.1 Schematic Layout of MFD

Figure 2 presents the components included in the development of the prototype. Electricity enters and is stored in the system by manual initial charging using the hybrid hand crank generator. The energy stored in the battery is converted from DC to AC by the inverter and is made available for consumption of the electric fan, induction cooker, flat television, amplifier, and fan. The electric fan provides motion to a connected DC motor which provides DC current to the timer control circuit. The DC power may be used for other purposes through the extension.

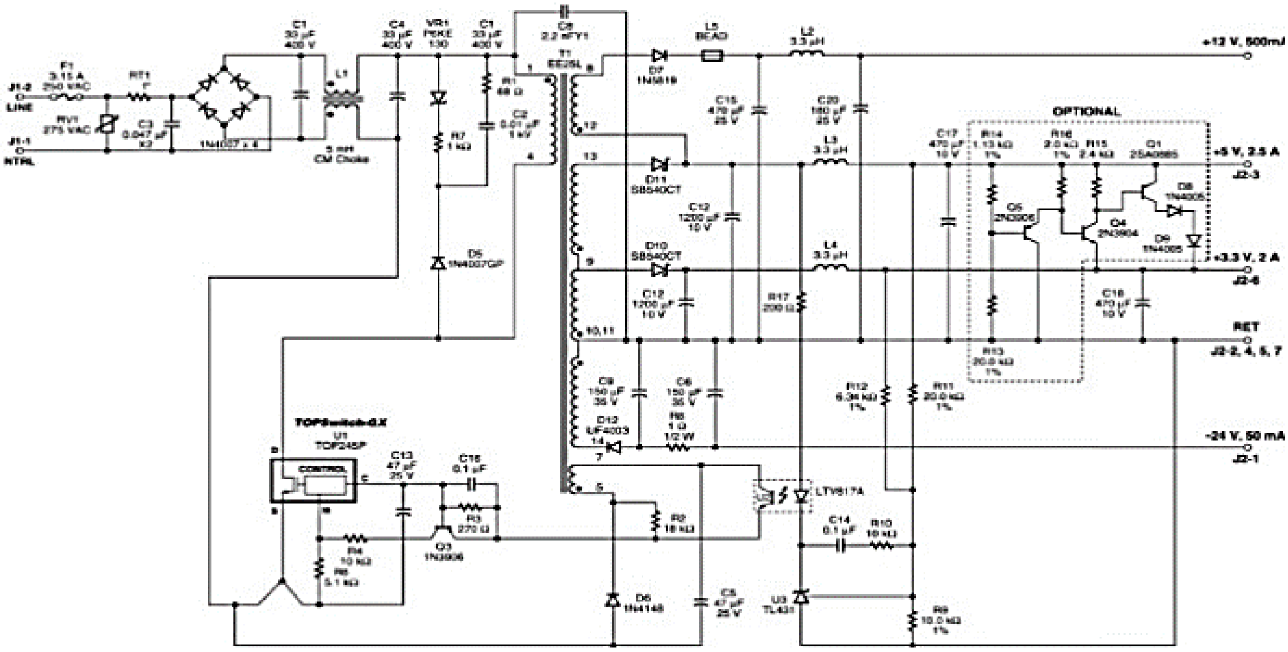

Fig 2. Schematic Diagram.

Figure 3 shows the internal layout and components within the circuitry of the power supply of the prototype. It can be seen that a rectifier unit was used in order to increase the power in the AC phase and converted multiple voltage outputs at the DC phase with values of 12V, 3.3V, and 24V.

The modular lay-out of the individual functions of the prototype is shown in Figure 5. It can be seen that there are AC and DC inputs, both of which are consolidated at the charge controller. It is also noticeable that every module is connected modularly in parallel to the power supply.

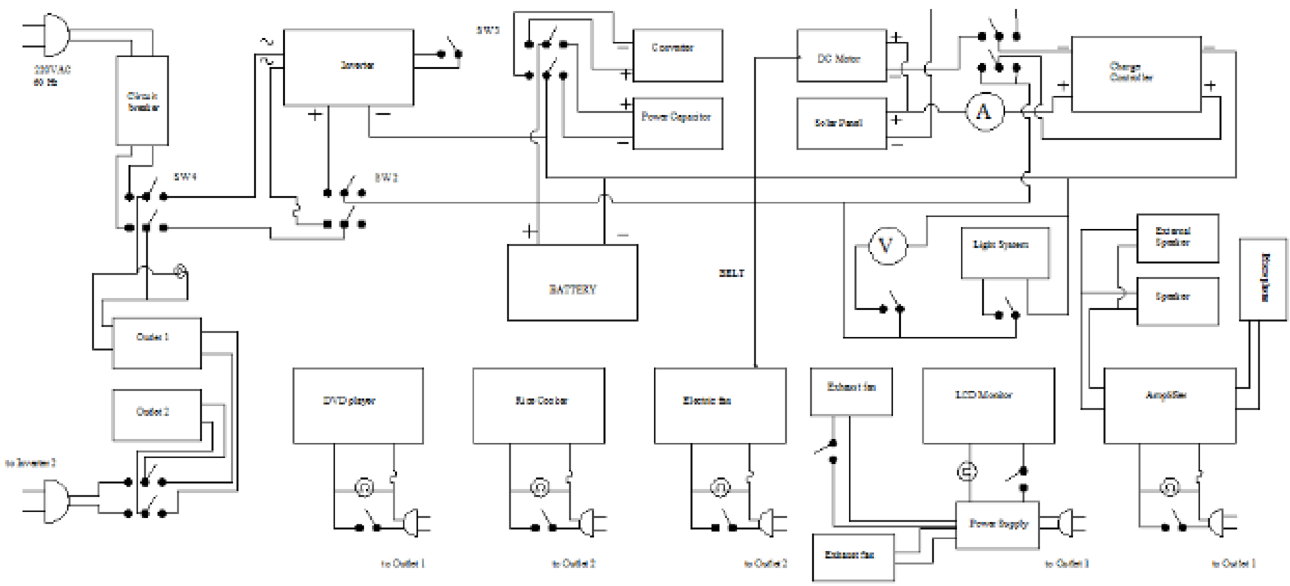

Fig 3. Schematic Diagram of Multi-functional device.

3.2 Level of Acceptability in terms of Functionality

Of the three groups of respondents, the second group of industry experts recorded the highest composite mean of 3.83, verbally interpreted as "Excellent". It is followed by the first group and expert groups, both with composite mean of 3.77, with qualitative description of "Excellent" also.

Table 1. Acceptability of the Multi-functional Device in terms of Functionality.

	Industry Experts Group A		Industry Experts Group B		Industry Experts Group C	
Ease of Operation	3.60	E	3.80	E	3.80	E
Provision of Comfort and Convenience to the User	3.70	E	3.70	E	3.60	E
User-friendliness	3.80	E	3.90	E	3.90	E
Ability to provide 5 in 1 function plus 1	4.00	E	3.70	E	3.70	E
System recovery from power failures	3.70	E	3.90	E	3.80	E
Audio/video system operation	3.70	E	4.00	E	3.80	E
Serves as charging station	3.90	E	3.80	E	3.80	E
Composite Mean	3.77	E	3.83	E	3.77	E
Overall					3.79	E

The overall mean is 3.79 or "Excellent." Results reveal that the prototype has excellent functionality, therefore, the MFD promises to be a very useful home appliance.

3.3 Level of Acceptability in terms of Economy

Table 2 shows the level of acceptability of the multi-functional device in terms of its economy, as evaluated by the respondents.

Table 2. Acceptability of the Multi-functional Device in terms of Functionality.

	Industry Experts Group A		Industry Experts Group B		Industry Experts Group C	
Restoration and Transformation of the old devices	3.80	E	4.00	E	3.90	E
Reduction of E-wastes	3.80	E	3.90	E	3.70	E
Recycling of E-wastes	3.90	E	4.00	E	3.80	E
Ability to self-generate energy	4.00	E	3.80	E	4.00	E
Re-use of locally available spare parts	3.90	E	3.90	E	3.90	E
AC/DC/Solar power compatibility	3.90	E	4.00	E	3.80	E
Composite Mean	3.88	E	3.93	E	3.85	E
Over All					3.89	E

Again, of the three groups of respondents, the second group recorded the highest composite mean of 3.93, qualitatively interpreted as "Excellent". This is followed by the first group and then the third group with composite means of 3.88 and 3.85, respectively, both falling under the verbal interpretation of "Excellent". The verbal description of "Excellent" applies also to the overall mean of 3.89, implying that the prototype is a highly economical device. This desirable characteristic makes the MFD a valuable device especially nowadays when inflation is on the rise.

3.4 Level of Acceptability in terms of Maintainability

The level of acceptability of the multi-functional device concerning maintainability is presented in Table 3.

Table 3. Acceptability of the Multi-functional Device in terms of Maintainability.

	Industry Experts Group A		Industry Experts Group B		Industry Experts Group C	
Replace-ability of the panel control system	3.50	E	3.80	E	3.70	E
Applicability of lighting system	3.60	E	3.80	E	3.70	E
Systematic electrical wiring connection	3.60	E	3.90	E	3.90	E
Removable/ Detachable speaker system	3.70	E	3.90	E	3.80	E
Adjustable cooling system	3.80	E	4.00	E	3.90	E
Easy to maintain battery pack	4.00	E	3.90	E	3.80	E
Movable Housing/casing system	3.90	E	4.00	E	3.70	E
Composite Mean	3.73	E	3.90	E	3.79	E
Over All					3.81	E

The second groups' assessment yielded the highest rating, as shown by the composite mean of 3.90 compared to the first groups' 3.73 and the third groups' 3.79. However, all these three ratings fall under the verbal description of "Excellent". The over-all mean is 3.81 or "Excellent."

Findings reveal that the multi-functional device possesses very high level of maintainability, indicating that it is very easy to keep the MFD in its most desirable condition. It can be done easily through cleaning and acquisition of parts to replace damaged parts. This characteristic is very important because everyone desires to own something that will last for many years of use.

3.5 Level of Acceptability in terms of Safety

Table 4 shows the level of acceptability of the multi-functional device in terms of its safety.

Table 4. Acceptability of the Multi-functional Device in terms of Safety.

	Industry Experts Group A		Industry Experts Group B		Industry Experts Group C	
Installed protection devices	3.90	E	4.00	E	3.90	E
Ventilation	3.90	E	4.00	E	4.00	E
Centralized timer circuit	3.80	E	4.00	E	4.00	E
Grounding system	3.80	E	4.00	E	3.90	E
Safety from physical hazards caused by noise, vibration, energy, heat, and electricity	3.60	E	3.90	E	4.00	E
Safety operational manual	3.60	E	3.60	E	3.80	E
Composite Mean	3.77	E	3.92	E	3.93	E
Over All					3.87	E

The third group registered the highest composite mean of 3.93 of the three groups of respondents. Coming very closely is the second group with a composite mean of 3.92. The first group recorded the lowest composite mean of 3.77. The 30 respondents' over-all mean is 3.87. All these numerical values are within the qualitative description of "Excellent," indicating the excellent level of safety when using the MFD. With this commendable characteristic of this multi-functional device, there is high possibility of marketability when this device is manufactured for public use.

4. CONCLUSION

In conclusion, this study addresses the urgent need for effective e-waste management in the Philippines by proposing an innovative approach that combines reuse, refurbishment, repair, and recycling to develop a multifunctional device from discarded electronic components.

Based on the evaluation of the thirty (30) respondents on the multi-functional device in relation to functionality, economy, maintainability, and safety, the analysis of composite mean scores across categories highlights key insights into the prototype's performance. Economy ranked the highest, with a composite mean of 3.89, indicating that the prototype is perceived as cost-effective. This result suggests that the design is economically viable, potentially making the device accessible to a wide range of users. Safety followed with a composite mean of 3.87, showing a strong perception of the prototype as safe for use. Given the importance of safety for user adoption, this high score enhances the device's usability, though slight improvements could further boost user confidence.

Maintainability, with a composite mean of 3.81, ranked third. This suggests that while the device is generally easy to maintain, there may be opportunities for optimizing maintenance requirements. Improved maintainability could extend the device's lifespan and lower long-term costs, contributing to user satisfaction. Functionality ranked lowest with a composite mean of 3.79, suggesting that while the prototype performs its intended functions adequately, there may be specific areas that require further refinement. Enhancing functionality would increase the prototype's practical value and user appeal, making it more versatile and effective in various applications.

The overall evaluation achieved a composite mean of 3.84, reflecting a generally positive reception of the prototype across all categories. This score indicates that the device meets essential user expectations but suggests that improvements in functionality and maintainability could enhance its overall performance. These findings provide a clear foundation for targeted refinements, supporting future iterations of the device to better meet user needs and market demands.

REFERENCES

[1] L. Luther, "Managing Electronic Waste: Issues with Exporting E-Waste," Congressional Research Service, Sep. 27, 2010. [Online]. Available: https://sgp.fas.org/crs/misc/R40850.pdf

[2] K. Lundgren, *The global impact of e-waste: Addressing the Challenge,* International Labour Organization, Geneva, 2012. [Online]. Available: https://www.saicm.org/Portals/12/Documents/EPI/ewastesafework.pdf

[3] G. Radha, "A Study of the Performance of the Indian IT Sector," 2022. [Online]. Available: http://www.nautilus.org

[4] Department of Information Technology, *Environmental Management for Information Technology Industry in India,* Government of India, pp. 122–124.

[5] M. Bhutta, A. Omar, and X. Yang, "Electronic Waste: A Growing Concern in Today's Environment," *Economics Research International,* vol. 2011, Art. no. 474230, Jun. 11, 2011. doi: 10.1155/2011/474230

[6] J. Puckett, L. Byster, S. Westervelt, R. Gutierrez, S. Davis, and A. Hussain, *Exporting Harm: The High-Tech Trashing of Asia,* Basel Action Network, Feb. 25, 2002.

[7] H. Mehra, "PC waste leaves toxic taste," *The Tribune,* Mar. 22, 2004.

[8] J. Cui and E. Forssberg, "Mechanical Recycling of Waste Electric and Electronic Equipment: A Review," *Journal of Hazardous Materials,* vol. 99, no. 3, pp. 243–263, 2003. doi: 10.1016/S0304-3894(03)00061-X

[9] H. Kang and J. Schoenung, "Used consumer electronics: A comparative analysis of materials recycling technologies," in *Proc. IEEE Int. Symp. Electronics and the Environment,* 2004. doi: 10.1109/ISEE.2004.1299720