Recycling and Reusing Components from Keypad Phones: A Reverse Engineering Approach

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***Abstract*—This paper presents a systematic approach to recycling keypad phones through reverse engineering techniques. The methodology includes disassembly, component evaluation, printed circuit board (PCB) processing, and metal recovery. Various chemical processes for the removal of epoxy layers and copper extraction are analyzed. Economic and environmental impacts of mobile phone recycling are discussed, along with challenges faced during the experiment. The findings demonstrate that with appropriate techniques, valuable materials and components can be recovered from end-of-life electronic devices, contributing to a circular economy and reduced e-waste. This study provides insights into sustainable practices for electronic waste management and resource recovery.**

***Index Terms*—reverse engineering, e-waste, recycling, keypad phones, copper recovery, PCB recycling, urban mining, circular economy**

I. Introduction

The proliferation of electronic devices has led to an unprecedented increase in electronic waste (e-waste). According to the Global E-waste Monitor 2024, approximately 65 million tonnes of e-waste were generated worldwide in 2023, with only 17.4% formally documented as properly collected and recycled [1]. Mobile phones constitute a significant portion of this waste stream, with an estimated 1.6 billion mobile phones discarded annually [2].

Keypad phones, though less prevalent than smartphones in many markets, still represent a substantial portion of devices in use globally, particularly in developing regions. These devices contain various valuable materials, including copper, gold, silver, palladium, and reusable electronic components that can be recovered through proper recycling techniques [3].

Reverse engineering offers a methodical approach to understanding the composition of these devices and extracting value from them. This paper documents a reverse engineering process for keypad phones with a focus on component reuse and material recovery, providing insights into both the technical aspects and the economic and environmental implications of mobile phone recycling.

II. Methodology

The reverse engineering process followed a systematic approach consisting of four main phases: disassembly, component evaluation, PCB processing, and metal recovery.

A. Disassembly Process

The keypad phone was carefully disassembled into its constituent parts using precision screwdrivers and plastic prying tools to avoid damage to reusable components. The disassembly followed a hierarchical approach:

1) Removal of battery and external covers
2) Separation of keypad mechanism and display module
3) Extraction of speaker, microphone, and vibration motor
4) Removal of the main PCB from the housing
5) Separation of antennas and connectors

Each component was documented and categorized based on potential for reuse or recycling.

B. Component Evaluation

After disassembly, components were visually inspected for physical damage and tested for functionality where possible. Components deemed reusable after quality check included:

- Display modules
- Speaker and microphone assemblies
- Vibration motors
- Keypads and buttons
- Battery connectors

These components were cleaned using isopropyl alcohol to remove dust and residue before being categorized for potential reapplication in other electronic devices or educational purposes.

C. PCB Processing

The PCB processing involved several steps to recover valuable materials:

1) Desoldering: All integrated circuits (ICs), capacitors, resistors, and other electronic components were carefully desoldered from the PCB using a specialized desoldering station. The recovered components were sorted by type and functionality for potential reuse after testing.

2) Solder Removal: Remaining solder was removed from the PCB using a commercial solder strip that facilitates desoldering through capillary action. This step was crucial to prevent contamination in subsequent chemical processes.

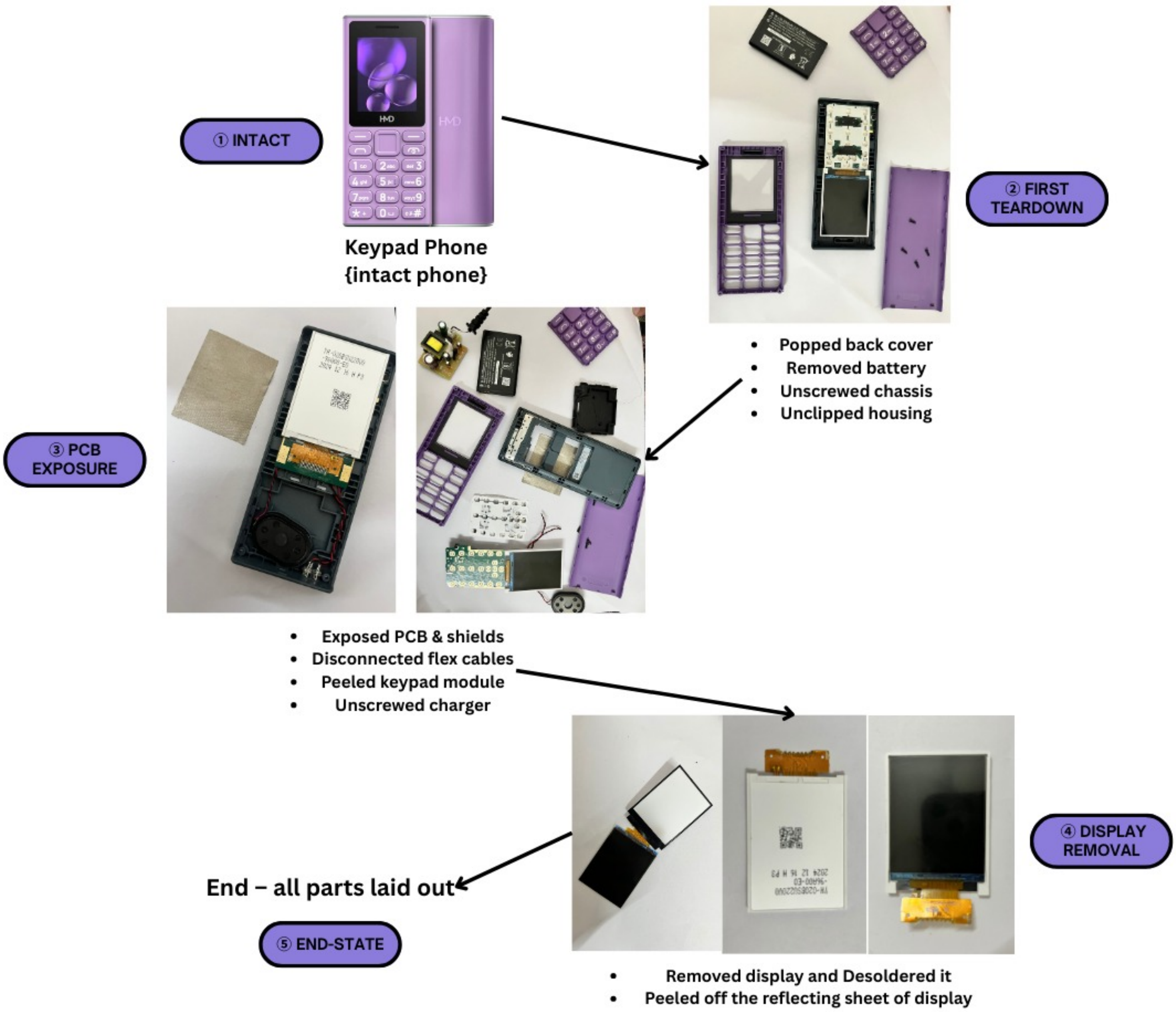
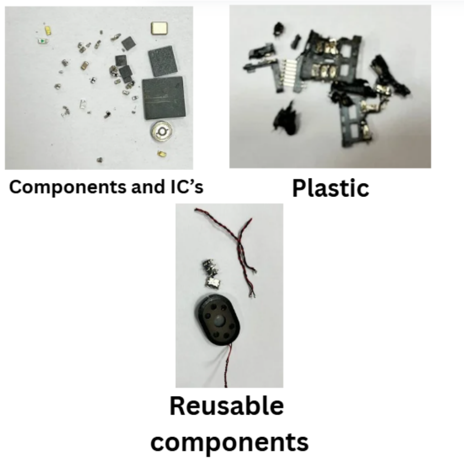


Fig. 1. Disassembly Process



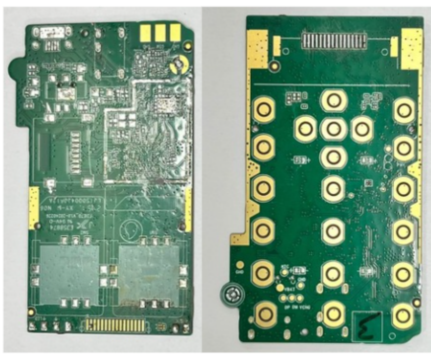


Fig. 2. Desoldered PCB

3) Epoxy Layer Removal: The protective epoxy layer covering the PCB was removed using a sodium hydroxide (NaOH) solution. The process involved:

- Preparing a 3M NaOH solution
- Heating the solution to approximately $100\,^{\circ}\mathrm{C}$
- Immersing the PCB in the heated solution for 30 minutes
- Rinsing thoroughly with deionized water
- Drying the PCB completely

This process successfully removed the epoxy layer, exposing the underlying copper traces and facilitating further processing.

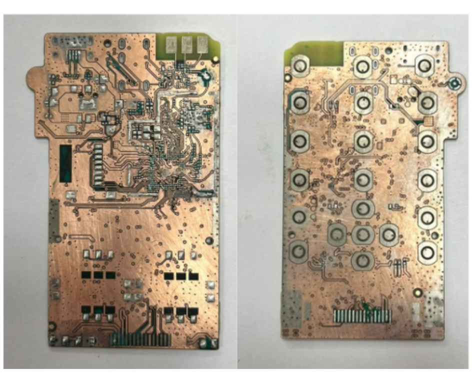


Fig. 3. Epoxy Layer Removal

4) Attempted Thermal Processing: An attempt was made to extract copper through thermal processing by heating the PCB to approximately $300\,^{\circ}\mathrm{C}$ in a controlled environment. However, this approach proved ineffective for several reasons:

Fig. 4. Oven

- The multilayer structure of the PCB prevented effective separation of materials
- The temperature achieved ($300\,^{\circ}\mathrm{C}$) was insufficient to melt copper (melting point $1085\,^{\circ}\mathrm{C}$)
- Toxic fumes were produced during heating due to the presence of flame retardants and other chemicals in the PCB

Temperatures exceeding $400\,^{\circ}\mathrm{C}$ were determined to be necessary for effective thermal recovery of copper, which was beyond the capabilities of the available equipment and raised significant safety concerns.

D. Copper Extraction from Printed Circuit Boards

1) Theoretical Background: The extraction of copper from PCBs typically involves several approaches, with mechanical crushing followed by chemical leaching being the most efficient. The chemical reactions primarily rely on oxidizing copper metal into copper ions in solution, which can then be recovered through precipitation or electrochemical methods.

2) Experimental Constraints: The optimal approach for copper extraction from PCBs involves crushing the boards and leaching them over an extended period. This method maximizes surface area contact between the leaching solution and copper components, resulting in higher extraction efficiency. However, due to the unavailability of suitable crushing equipment in our laboratory, we were compelled to investigate alternative methods that could work with intact PCB pieces.

3) Methodological Approaches Considered: We evaluated two potential chemical extraction pathways:

1) **Sequential extraction:** Using H_2SO_4 to first remove iron components, followed by a mixture of HNO_3 and

H_2O_2 to selectively extract copper while preserving the FR4 substrate integrity.

2) **Direct oxidative leaching:** Employing a mixture of H_2SO_4 and H_2O_2 as a potent oxidizing solution to convert copper directly into copper sulfate.

We proceeded with the second approach due to reagent availability and process simplicity.

4) Experimental Procedure: The copper extraction was conducted as follows:

- **Solution preparation:** A leaching solution was formulated by carefully mixing $18\,\mathrm{mL}$ of concentrated sulfuric acid (H_2SO_4), $10\,\mathrm{mL}$ of hydrogen peroxide (H_2O_2, 30
- **Solution activation:** The prepared solution was heated to $50\,^{\circ}\mathrm{C}$ using a controlled heating mantle to accelerate the oxidation reaction while maintaining temperature below the degradation point of the FR4 substrate.
- **PCB immersion:** A pre-cleaned PCB sample was completely immersed in the heated solution. The following reaction was expected to occur:

$$\mathrm{Cu} + \mathrm{H_2SO_4} + \mathrm{H_2O_2} \longrightarrow \mathrm{CuSO_4} + {}_2\mathrm{H_2O} \qquad (1)$$

- **Copper precipitation:** After sufficient leaching time (approximately $30\,\mathrm{min}$), the solution containing copper sulfate ($CuSO_4$) was separated from PCB residues. Iron filings would have been added to precipitate elemental copper through a displacement reaction:

$$\mathrm{Fe} + \mathrm{CuSO_4} \longrightarrow \mathrm{FeSO_4} + \mathrm{Cu} \qquad (2)$$

5) Results and Observations: The process demonstrated successful extraction of copper from the PCB into solution, as evidenced by:

- Initial formation of a blue copper sulfate solution, confirming the oxidation of metallic copper

However, several challenges were encountered:

- **Thermal management issues:** Despite attempts to maintain temperature at $50\,^{\circ}\mathrm{C}$, localized overheating of the FR4 substrate occurred, resulting in thermal degradation

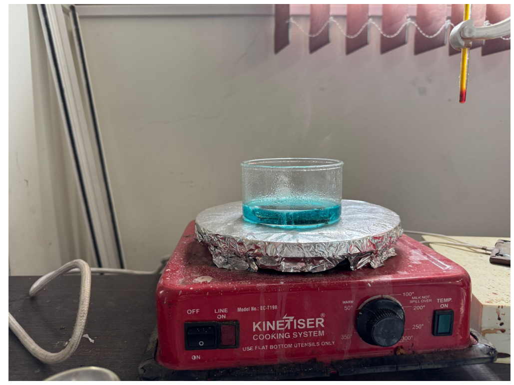


Fig. 5. Copper Sulfate Solution

- **Carbon contamination:** The overheating of the FR4 material led to oxidation of the polymer matrix into carbon, creating a black sludge that contaminated the reaction mixture

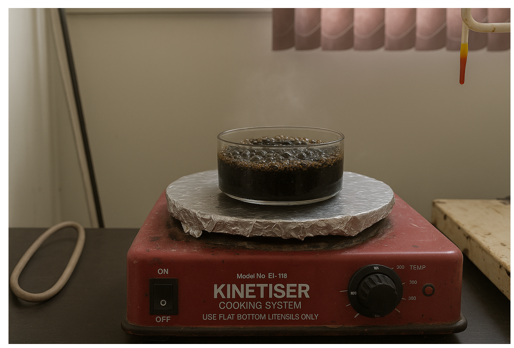


Fig. 6. Black Sludge

6) Process Optimization Insights: Based on our experimental observations, several factors require optimization for improved copper extraction:

- **Temperature control:** Maintaining temperature strictly below $45\,^{\circ}\mathrm{C}$ may prevent FR4 degradation while still allowing copper oxidation
- **Solution concentration:** A more dilute solution with gradual addition of oxidizing agent could provide better control over the reaction rate
- **Mechanical preparation:** Even without crushing equipment, cutting PCBs into smaller pieces would increase surface area and improve extraction efficiency

7) Conclusion: Although our experiment using H_2SO_4/H_2O_2 successfully demonstrated copper extraction from PCBs into solution in the form of $CuSo_4$, the ideal approach remains mechanical crushing followed by chemical leaching. The challenges encountered with substrate degradation highlight the importance of precise reaction control when working with composite materials like PCBs. For future experiments, we recommend exploring:

- Lower concentration leaching solutions applied over longer periods

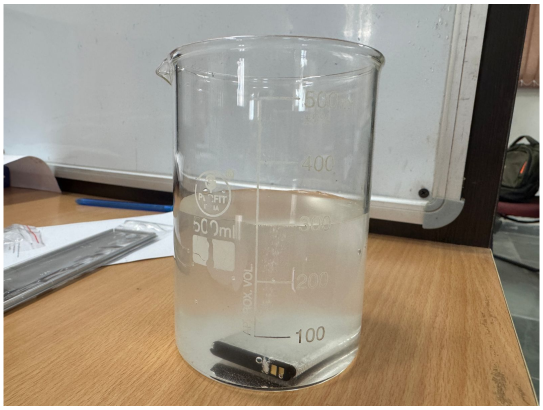


Fig. 7. Battery Discharging

- Two-stage extraction processes that separate the oxidation and dissolution steps
- Alternative mechanical preprocessing methods that can be implemented with basic laboratory equipment

E. Battery Recycling Process

The lithium-ion battery from the keypad phone underwent a separate recycling process to safely recover valuable materials while mitigating environmental and safety risks:
Prior to disassembly, the lithium-ion battery was safely discharged to minimize risk of thermal runaway or explosion:

- A saturated sodium chloride (NaCl) solution was prepared in a non-metallic container
- The battery was completely submerged in the salt solution
- The system was left undisturbed for 7 days in a well-ventilated area
- Hydrogen gas evolution was observed and collected during the discharge process
- Voltage measurements were taken daily to confirm gradual discharge to below $0.5\,\mathrm{V}$

The chemical reaction during discharge in salt solution can be represented as:

$$\text{Cathode: } Li_{1-x}CoO_2 + xLi^+ + xe^- \longrightarrow LiCoO_2 \quad (3)$$

$$\text{Anode: } LiC_6 \longrightarrow Li_{1-x}C_6 + xLi^+ + xe^- \quad (4)$$

$$\text{In salt solution: } 2H_2O + 2e{-}{-} > H_2 + 2OH^- \quad (5)$$

After complete discharge, the battery was carefully disassembled in a fume hood following safety protocols:

1) Removal of the outer metal casing using ceramic tools to prevent short circuits
2) Separation of the polymer separator from the electrode materials
3) Unfolding and segregating the copper foil (anode current collector)
4) Collection of aluminum foil (cathode current collector)
5) Scraping and collection of cathode material (primarily $LiCoO_2$)

Fig. 8. Hydrogen Collection

6) Separation of graphite material from copper substrate

1) Material Recovery: The components obtained from battery disassembly were quantified and prepared for further processing:

TABLE I
MATERIALS RECOVERED FROM LITHIUM-ION BATTERY

Component	**Mass (g)**
Copper foil	4.3
Aluminum casing	5.0
Cathode material ($LiCoO_2$)	4.1
Graphite	1.8
Connectors/tabs	0.3
Plastic	3

Fig. 9. Battery Constituents

Complete separation of lithium and cobalt would require additional steps such as solvent extraction or precipitation, which were beyond the scope of this experiment. However, the leachate solution containing these valuable elements was preserved for potential future processing.

III. Results and Discussion

A. Component Recovery and Reuse

The disassembly and evaluation process yielded approximately 60% of components potentially suitable for reuse in repair operations, educational purposes, or other electronic projects. Table II summarizes the recovered components and their potential applications.

TABLE II
RECOVERED COMPONENTS AND POTENTIAL APPLICATIONS

Component	Condition	Potential Application
LCD Display	Good	Repair, educational projects
Keypad rubber	Excellent	Reusage
Speaker	Good	Audio projects, repair
Microphone	Good	Audio recording projects, repair
Capacitors/Resistors	Variable	Electronic circuit building

B. Challenges and Limitations

Several challenges were encountered during the reverse engineering process:

1) Multilayer PCB Complexity: The multilayer structure of the PCB significantly complicated the material recovery process. Unlike single-layer PCBs, where copper traces are easily accessible, multilayer PCBs contain embedded copper layers that are difficult to separate using conventional methods.

2) Temperature Limitations: The attempted thermal processing was limited by equipment capabilities and safety considerations. Higher temperatures ($>400\,^{\circ}$C) would be required for effective copper melting, but would also pose increased risks of toxic emissions and fire hazards.

3) Chemical Handling Safety: The chemical extraction process involved hazardous substances, including concentrated sulfuric acid and hydrogen peroxide. Proper safety equipment and ventilation were essential, limiting the scalability of this approach in non-laboratory settings.

4) Component Compatibility: While many components were physically intact, their compatibility with current electronic systems may be limited due to technological obsolescence. This factor reduces the practical value of some recovered components despite their functional integrity.

C. Economic Analysis

The economic viability of the recycling process was analyzed based on material recovery value and processing costs, with all figures converted to Indian Rupees (INR).

1) Material Value: Based on current market prices, the materials recovered from a single keypad phone have the following approximate values:

- Copper: $1.2\,\mathrm{g}$ × INR 625/kg = INR 0.75
- Aluminum: $5.0\,\mathrm{g}$ × INR 220/kg = INR 1.10
- Cobalt (from battery): $1.5\,\mathrm{g}$ × INR 350/kg = INR 0.53
- Lithium (from battery): $0.3\,\mathrm{g}$ × INR 900/kg = INR 0.27
- Reusable electronic components:
  - LCD Display: INR 50-80 (depending on condition)
  - Speaker: INR 10-15
  - Microphone: INR 8-12
  - Keypad assembly: INR 15-20
  - Battery connector: INR 3-5
  - Antenna: INR 4-7
  - Various ICs, capacitors, resistors: INR 20-40

Total material value per phone: INR 112.65 - 181.65

2) Processing Costs: The estimated processing costs per phone include:

- Chemicals:
  - Sodium hydroxide (NaOH): INR 5
  - Sulfuric acid (H_2SO_4): INR 6
  - Hydrogen peroxide (H_2O_2): INR 4
  - Sodium chloride solution (for battery discharge): INR 1.50
  - Miscellaneous: INR 25

Total processing cost per phone: INR 41.5

3) Economic Viability: Based on these calculations, the process shows positive economic viability on a per-phone basis, with potential profit ranging from INR 112.65 - 181.65 per device. Economies of scale could significantly improve these figures, as many costs would be distributed across larger volumes of processed devices.

Moreover, the analysis does not account for the avoided costs of e-waste disposal, which can range from INR 150 to INR 400 per device in many urban areas [5]. When these avoided costs are considered, the economic case becomes substantially more favorable.

TABLE III
ECONOMIC ANALYSIS SUMMARY (IN INR)

Category	Amount (INR)	Notes
Material Value	112.65 - 181.65	Includes metals and reusable components
Processing Cost	41.5	Includes chemicals, energy, overhead, etc.
Net Profit/Loss	71.15 - 140.15	Before scaling advantages
Avoided Disposal Cost	150 - 400	Additional economic benefit
Total Economic Benefit	221.15 - 540.15	Including avoided disposal costs

4) Scalability Analysis: For a medium-scale operation processing 1,000 phones monthly, economies of scale would yield additional benefits:

- Bulk purchase of chemicals: 30% reduction in chemical costs
- Improved material recovery rates through specialized equipment: 10% increase in yield
- Lower overhead per unit: 20% reduction
- More efficient energy usage: 15% reduction in energy costs
- Optimized water recycling: 25% reduction in water-related costs

At this scale, the profit margin could increase to approximately INR 110-160 per device, representing a 126-121% improvement over single-unit processing.

5) Economic Impact on E-waste Ecosystem: The financial viability demonstrated in this analysis suggests that formal recycling of keypad phones could create sustainable business opportunities in the e-waste management sector. For a medium-scale facility processing 12,000 phones annually, this represents a potential revenue stream of INR 2.16-2.88 million per year from recovered materials alone.

Additionally, the establishment of such facilities could generate indirect economic benefits through:

- Development of local collection networks
- Creation of skilled technical positions
- Reduction in municipal waste management costs
- Growth of secondary markets for refurbished components

IV. Environmental Impact and Circular Economy

The reverse engineering and recycling of keypad phones align with circular economy principles, emphasizing sustainable use of resources through reuse, refurbishment, and recycling. By extending the lifecycle of components, this approach reduces electronic waste and minimizes the demand for raw materials. The modular design of older keypad phones simplifies disassembly, enabling efficient recovery of materials such as metals, plastics, and semiconductors. Implementing these practices not only mitigates environmental harm but also contributes to economic resilience by reclaiming valuable resources and reducing manufacturing costs.

A. Circular Economy in Practice

The circular economy model promotes a closed-loop system where products and materials are continuously repurposed, minimizing waste and resource consumption. In the context of keypad phones, this involves systematic disassembly, testing, and re-utilization of functional components. Materials such as copper, gold, and rare earth metals are recovered and reintegrated into the manufacturing cycle, reducing the need for virgin resource extraction. Furthermore, non-recyclable components are processed to minimize environmental impact. This project embodies circular economy principles by extending product lifecycles and fostering sustainable consumption patterns, contributing to both environmental conservation and economic sustainability.

V. Economic Impact

Reverse engineering of keypad phones not only contributes to environmental sustainability but also holds significant economic potential. By salvaging functional components like displays, and integrated circuits, the project reduces dependency on purchasing new parts, cutting costs in prototyping and small-scale manufacturing. Furthermore, the recovery of valuable metals such as copper presents opportunities for material resale, contributing to financial returns.

The circular economy approach amplifies this impact by enabling a continuous cycle of material recovery and reuse. Reintegrating extracted materials into new electronic projects lowers the overall bill of materials (BOM) and reduces electronic waste handling costs. Additionally, reverse-engineered components serve as cost-effective substitutes for educational and prototyping applications, democratizing access to hardware for learning and experimentation.

The project also showcases the potential for local economic development through the establishment of small-scale electronic recycling and refurbishing hubs. By fostering skills in disassembly, testing, and materials recovery, it creates pathways for job creation and community-driven sustainable technology practices. ””

VI. Future Improvements

Based on the experiences and challenges encountered in this study, several potential improvements to the recycling process are identified:

- Automated disassembly systems could increase throughput and reduce labor costs
- More selective leaching agents could improve metal recovery efficiency while reducing chemical usage
- Implementation of hydrometallurgical processes for precious metal recovery (gold, silver, palladium)
- Development of standardized testing protocols for evaluating component reusability
- Integration with manufacturer take-back programs to establish closed-loop recycling systems

VII. Conclusion

This reverse engineering study demonstrates that keypad phones can be effectively recycled to recover valuable components and materials. The developed methodology, combining mechanical disassembly, component evaluation, and chemical processing, provides a framework for systematic e-waste processing.

While economic analysis reveals marginal profitability on a per-device basis, scaling effects and the inclusion of avoided disposal costs improve the financial viability. Furthermore, the environmental benefits of resource conservation, energy savings, and pollution reduction provide compelling additional justification for mobile phone recycling initiatives.

The challenges identified, particularly related to multilayer PCB processing and component compatibility, highlight the need for continued innovation in recycling technologies and design-for-recycling principles in electronics manufacturing.

This study contributes to the growing body of knowledge on urban mining and circular economy practices in the electronics sector, offering practical insights for both educational purposes and potential commercial applications in e-waste management.

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