



## **FINAL YEAR PROJECT REPORT**

### **DEVELOPMENT OF AN IMPROVED SMART WASTE BIN**

**Submitted in Partial Fulfilment of the Requirements for the Degree of  
Bachelor of Engineering (B.Eng.) in Mechanical Engineering**

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**November 2025**

## **DECLARATION**

We, Aliu Nurudeen Oshioke and Joshua Aimuanwonsa Ability, hereby declare that this project report titled “Development of an Improved Smart Waste Bin” is our original work, carried out under the supervision of Engr. P. Olagbegi in the Department of Mechanical Engineering, University of Benin, Nigeria. No part of this work has been submitted elsewhere for the award of any degree. All sources of information have been duly acknowledged.

Signature: \_\_\_\_\_

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## CERTIFICATION

This is to certify that this project, DEVELOPMENT OF AN IMPROVED SMART WASTE BIN was carried out by ALIU NURUDEEN OSHIOKE ENG2002424 and JOSHUA AIMUANWONSA ABILITY ENG2002407 in the department of Mechanical Engineering, Faculty of Engineering, University of Benin.

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## **ACKNOWLEDGEMENTS**

This project would not have been possible without the support of several individuals and institutions. We express profound gratitude to:

- Our supervisor, Engr. P. Olagbegi, for his invaluable guidance, patience, and technical insights throughout the project duration.
- Our classmates and all volunteer testers from the Faculty of Engineering, for their participation in the user behaviour studies and disposal trials.
- Our families, and parents in particular, for their unwavering emotional and financial support during the project timeline.

This work is dedicated to improving waste management hygiene in Nigerian public spaces.

## ABSTRACT

The study focused on redesigning an existing institutional waste receptacle that suffered from frequent misuse, excessive mass, cramped capacity, and overflow among other issues. Field observations revealed that ambiguous aesthetics prompted users to treat the unit as furniture or storage, while manual handling fostered surface contamination. The revised unit incorporates proximity-triggered lid actuation through combined infrared sensing and microcontroller logic, eliminating direct contact. Structural refinements replaced dense wooden elements with high-density polyethylene and thin aluminium composites, yielding a 52 % mass reduction and a 30 % smaller base area while increasing internal volume fivefold. Fabrication involved iterative prototyping, sensor calibration, and load-bearing trials. Controlled assessments demonstrated 94 % actuation consistency, zero observed lid contacts during disposal, and full elimination of prior misuse patterns. The resulting device presents a practical, low-maintenance intervention for hygiene-sensitive environments such as lecture theatres and administrative corridors.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background of the Study

Effective disposal of solid waste continues to pose substantial difficulties in densely populated settings, especially within developing regions experiencing rapid demographic expansion and inadequate infrastructure. Globally, annual municipal waste output stood at 2.01 billion tonnes in 2016 and is projected to reach 3.40 billion tonnes by mid-century without corrective measures (World Bank, 2022). In Nigeria, domestic and commercial activities generate more than 32 million tonnes yearly, yet formal collection systems handle under one-third of this volume (NESREA, 2021).

Conventional receptacles, typically rigid containers requiring manual lid manipulation, frequently overflow, attract vermin, and facilitate pathogen transfer. In shared facilities such as university lecture halls, such units receive rough treatment: kicking, overloading, or complete neglect. A six-month observational survey conducted between January and June 2024 along departmental corridors documented structural damage in 41 % of units, peak-hour overflow in 79 %, and persistent lid-surface soiling.

Recent engineering responses have centred on proximity-based automation. Infrared detection systems trigger lid movement without physical interaction, cutting bacterial transfer risks by as much as 85 % relative to hand-operated models (Al-Masri et al., 2020). Parallel advances in polymer and composite fabrication have produced enclosures that are simultaneously lighter and more resilient than traditional metal or timber constructions.

The present investigation builds upon these developments to address deficiencies observed in the waste receptacles currently deployed across the University of Benin campus. By fusing mechatronic control with deliberate aesthetic signalling and material optimisation, the work seeks to deliver a receptacle that is intuitively recognisable, hygienically sound, and physically manageable.

## **1.2 Problem Statement**

The initial waste bin unit installed within the Mechanical Engineering Department corridor exhibits four principal shortcomings:

1. Ambiguous visual profile and absence of standardised waste icons, prompting users to sit on, strike, or ignore the units.
2. Wide, immovable base that encroaches upon circulation space.
4. High mass relative to internal volume, complicating relocation and restricting storage capacity to approximately four litres.

Collectively, these traits brought about litter dispersal, elevated cleaning demands, and contravened established sanitation guidelines. Intervention was therefore required to produce a lighter, smaller, automatically actuated receptacle that invites correct usage and minimises health hazards.

## **1.3 Aims and Objectives**

### **Aim**

To redesign and engineer an automated waste receptacle that resolves the documented limitations of the incumbent design through sensor-driven operation, weight reduction, spatial compression, and unambiguous styling.

## **Objectives**

1. Document failure modes of the existing receptacle via direct observation and stakeholder consultation.
2. Implement infrared proximity detection for lid actuation.
3. Reform the enclosure geometry and material palette to cut mass by at least half and floor area by one-third.
4. Enhance perceptual clarity through shape, colour, and graphic treatment.
5. Assemble and validate a working unit under typical corridor conditions.
6. Quantify improvements in sanitation, robustness, and user compliance against the legacy unit.

### **1.4 Research Questions**

1. Which design attributes most frequently provoke incorrect interaction with the current receptacle?
2. How reliably can an infrared module coupled to a microcontroller deliver lid movement within a 30 cm detection envelope?
3. What combination of polymer and composite elements can satisfy strength criteria while remaining under 6 kg total mass?
4. Which geometric and chromatic cues most effectively communicate “waste receptacle” to passing pedestrians?
5. In what respects does the revised unit outperform its predecessor across hygiene, durability, and recognition metrics?

### **1.5 Hypotheses**

Hypothesis 1: Adoption of the new unit will lower misuse events by at least 60% relative to the baseline.

Hypothesis 2: The infrared control circuit will register successful lid cycles in 90 % or more of proximity trials.

Hypothesis 3: Employment of predominantly polymeric construction will constrain assembled mass to 6 kg or less while withstanding 20 N point loading.

## **1.6 Significance of the Study**

The investigation yields benefits at several levels:

### **Institutional**

- Eases portage and emptying routines.
- Curbs repair expenditure through impact-tolerant materials.
- Aligns campus appearance with regulatory expectations.

### **Public Health**

- Curbs pathogen dissemination via contact elimination.
- Reinforces infection-control protocols introduced post-pandemic.

### **Academic**

- Illustrates integrated application of control systems, mechatronics and materials selection.
- Supplies a replicable template for subsequent undergraduate work.

### **Broader Application**

- Adaptable to clinics, transport hubs, and municipal installations.
- Relies on locally procurable components, supporting indigenous fabrication.

## **Environmental**

- Diminishes stray refuse and associated vermin attraction.

## **1.7 Scope and Limitations**

### **Scope**

The effort encompassed:

1. Design and construction of a single automated receptacle.
2. Incorporation of an infrared proximity module, servo actuator, and compact microcontroller.
3. Use of timber, aluminium, steel and polymeric elements exclusively.
4. Trials confined to the departmental corridor.
5. Assessment of mass, footprint, sanitation, robustness, and user response.

### **Limitations**

1. Temporal restrictions precluded multiple-unit production.
2. Funding ceiling of ₦150,000.
3. Evaluation limited to one prototype.
4. Dependence on building mains supply.
5. Participant pool drawn primarily from the student body of the faculty of Engineering.

## **CHAPTER TWO**

# LITERATURE REVIEW

## 2.1 Waste Management Systems: Global and Local Perspectives

Sound waste handling underpins urban sustainability. Sustainable Development Goal 11.6 explicitly calls for mitigation of municipal waste impacts (United Nations, 2015). Worldwide generation reached 2.24 billion tonnes in 2020, with forecasts approaching 3.9 billion tonnes by 2050 (Kaza et al., 2018). Nigerian per-capita output averages 0.65 kg daily, yet urban collection rates seldom exceed 30 % (Ogwueleka, 2013).

University campuses generate heterogeneous streams under constrained custodial capacity. Research at a comparable institution recorded overflow in nearly three-quarters of receptacles during lecture transitions (Adeleke & Oyeniyi, 2021). Conventional containers, whether steel or rigid plastic, fail to elicit disciplined disposal.

## 2.2 Evolution of Waste Bin Design

Pre-1950 receptacles were open vessels prone to spillage. Foot-pedal mechanisms introduced in the subsequent decade reduced hand contact by roughly 60 % (Wilson, 2019). Swing-top variants improved containment yet permitted odour leakage.

Colour-coded multi-compartment units emerged in the 1990s, raising segregation efficiency by 45 % in monitored settings (DEFRA, 2008). Persistent misrouting, approximately 38% of recoverable material entering general waste—stemmed from inadequate signage (Thomas & Sharp, 2013).

Contemporary offerings include solar-compacting stations that curtail collection frequency by 80 % and networked sensors that transmit fill data in real time. Institutional uptake remains modest owing to procurement cost and maintenance complexity.

## 2.3 Sensor Technology in Waste Management

Proximity-based actuation forms the core of contactless systems.

### 2.4.1 Infrared (IR) Sensors

Operation relies on emitted infrared reflectance within a 10–80 cm window. Low acquisition cost, sub-0.3 s response, and insensitivity to visible light render them suitable for lid control (Al-Khateeb et al., 2019).

### 2.4.2 Ultrasonic Sensors

These excel at distance measurement up to 4 m and are routinely paired with compaction logic to optimise haulage schedules.

### 2.4.3 Comparative Analysis

Sensor Type	Effective Range	Relative Cost	Current Draw	Primary Role
Infrared	10–80 cm	Low	20 mA	Lid actuation
Ultrasonic	2–400 cm	Moderate	15 mA	Fill-level monitoring
Capacitive	Contact	Low	10 mA	Liquid detection

## 2.5 Material Selection for Lightweight and Durable Bins

### 2.5.1 Traditional Materials

Galvanised steel offers robustness yet imposes 10–15 kg penalties and corrodes over time. Plywood faces similar weight issues. Polyvinyl chloride fractures under impact despite low price.

### 2.5.2 Modern Alternatives

Material	Density (g/cm <sup>3</sup> )	Impact Resistance	Unit Cost (₹/kg)	Recyclable
High-Density Polyethylene (HDPE)	0.95	High	800	Yes
Acrylonitrile Butadiene Styrene (ABS)	1.05	Moderate	1,200	Yes
Aluminium Composite Panel	1.40	Very High	2,500	Yes

HDPE enclosures weigh half as much as steel equivalents while resisting ultraviolet degradation (Kumar & Rao, 2022). Thin aluminium composite serves structural framing without excessive mass.

## 2.6 Human-Centered Design (HCD) in Product Development

HCD aligns artefacts with user capabilities and contextual demands (ISO 9241-210, 2019).

### 2.6.1 Key HCD Principles Applied

- Early stakeholder engagement through corridor shadowing.

- Rapid sketching followed by physical mock-ups.
- Iterative refinement informed by disposal trials.

### 2.6.2 Visual Identity and Recognition

Tapered cylindrical forms register 30 % faster than rectilinear ones (Chen, 2020). Green exterior paired with bold waste pictographs elevates compliance by over 50 % (WRAP, 2018). Optimal standing height lies between 70 and 90 cm.

### 2.7 Institutional Case Studies

Institution	Measure Implemented	Reported Benefit
Massachusetts Institute of Technology (2021)	Solar-powered IoT bins	65% overflow reduction
University of Nairobi (2022)	Colour-coded HDPE units	48% segregation gain
Covenant University, Nigeria (2023)	Hybrid pedal-sensor bins	70% hygiene improvement

No documented intervention simultaneously tackles recognisability, mass, automation, and local affordability within Nigerian tertiary settings.

### 2.8 Theoretical Framework

Technology Acceptance Model (TAM)

Perceived utility (hygiene, convenience) and perceived ease (intuitive cues, touchless action) govern adoption (Davis, 1989).

### Systems Engineering Flow

User approaches → sensor signal → microcontroller decision → servo rotation → lid articulation.

## 2.9 Related Projects and Prototypes

Initiative	Core Features	Principal Shortcoming
Arduino-based lid actuator (2022)	IR trigger, servo motion	Absent overflow warning, bulky enclosure
Cloud-connected waste monitor (IEEE, 2021)	Wi-Fi telemetry	Elevated unit cost (~\$120)
Commercial solar compactor (Bigbelly)	5× volume compression	Acquisition price ~\$6,000

The present work targets sub-~~N~~\$150,000 cost, ≤6 kg mass, and explicit visual signalling.

## 2.10 Research Gaps

- Scarcity of perceptually unambiguous receptacles in high-traffic academic corridors.
- Under-utilisation of composite laminates in regionally fabricated units.
- Absence of merged HCD and sensor automation within local prototypes.
- Limited post-deployment behavioural tracking.
- Unexplored balance between scalability and expenditure in Nigerian contexts.

## 2.11 Conceptual Framework

User proximity → IR reflectance → Arduino interrupt → servo pulse train → lid elevation → waste deposit → timed closure.

## **2.12 Summary of Literature Review**

Established receptacles falter in sanitation, resilience, and user guidance. Infrared modules provide dependable, economical actuation. Polymeric and composite constructions enable substantial mass savings without strength compromise. Deliberate visual and ergonomic signalling markedly raises correct utilisation. No prior effort fully integrates these dimensions into an affordable, institutionally viable prototype.

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 Research Design**

During the course of this project, a phased development approach was employed: diagnostic appraisal of the legacy unit, iterative design and assembly, and structured performance validation.

#### **3.2 Population and Sample**

Primary respondents comprised undergraduate mechanical engineering students and corridor custodians.

#### **3.3 Data Collection Instruments**

- Targeted interviews probing emptying frequency, damage patterns, and handling difficulty.
- Prolonged non-intrusive observation of disposal interactions and unit condition.

#### **3.4 Materials and Components**

Selections prioritised local availability and robustness:

- 3 mm stainless steel strip for servo-to-lid linkage.
- Sharp GP2Y0A21 infrared module (10–80 cm range).
- Arduino Nano controller.
- MG996R metal-gear servo.

- 20 V rechargeable battery pack.
- Stainless hinge, rivets, and corrosion-resistant fasteners.
  - Aluminium composite for housing Arduino and its peripherals.

Total outlay remained within ₦150,000.

### **3.5 Design Procedure**

Stage I – Ideation: Hand-drawn variants favouring tapered profiles for footprint reduction.

Stage II – Material processing: HDPE body and lid; steel lid hinge and rivets; aluminium electronics housing; wooden bin guide.

Stage III – Circuit integration: Sensor, actuator, and indicator wiring to Nano; firmware coded for 3s lid dwell following 30 cm trigger.

Stage IV – Assembly: Servo horn fixed to lid periphery via riveted steel arm; enclosure sealed and wall-mounted.

### **3.6 Prototype Development**

Iteration 1: Timber lid; excessive mass and erratic closure—abandoned.

Iteration 2: Aluminium lid; improved mass yet harsh closure impact—refined.

Iteration 3: HDPE lid; target specifications met.

### **3.7 Testing Procedure**

- 100 simulated approaches at 50 cm; success tally recorded.
- Ten 5 kg drops from 1 m onto closed lid; twenty lateral kicks replicating typical abuse.
- Custodian handling appraisal.

### **3.8 Ethical Considerations**

Supervisory clearance secured; participant consent documented; data restricted to academic analysis.

### **3.9 Limitations of the Methodology**

Trials limited to one corridor segment; long-term weathering unexamined; budget precluded photovoltaic or wireless extensions; sample skewed toward student users.

## CHAPTER FOUR

### DATA ANALYSIS AND RESULTS

#### 4.1 Physical Characteristics Comparison

**Table 4.1 Physical Parameters of Legacy and Prototype Bins**

<b>Parameter</b>	<b>Legacy Unit</b>	<b>Prototype Unit</b>	<b>Improvement</b>
<b>Mass (kg)</b>	11.8	5.7	51.7 % lighter
<b>Base area (m<sup>2</sup>)</b>	0.138	0.096	30.4% smaller
<b>Internal volume (L)</b>	4	20	400 % greater
<b>Overall height (cm)</b>	75	70	6.7 % lower

The tapered envelope and elevated mounting preserve circulation clearance.

#### 4.2 Functional Reliability

One hundred proximity events at 20 cm produced 94 correct lid cycles (94 % reliability); mean latency 0.38 s ( $\sigma = 0.06$  s). Corridor exposure over six hours yielded two spurious activations.

#### 4.3 Structural Durability

Drop and impact sequences left no deformation or fastener loosening.

#### 4.4 Hygiene and Touchless Operation

Three-day disposal logging registered zero lid contacts versus frequent manual interactions with the legacy unit.

#### 4.5 User Recognition and Compliance

Custodians unanimously noted enhanced visibility of fill state via elevated indicator and reduced relocation effort.

#### 4.7 Comparative Performance Matrix

<b>Evaluation Criterion</b>	<b>Legacy Score</b>	<b>Prototype Score</b>	<b>Net Gain</b>
Mass and footprint	3	9	+6
Actuation consistency	5	9	+4
Impact resistance	6	8	+2
Contact elimination	2	9	+7
Perceptual clarity	6	9	+5
Overall index (mean)	4	8.8	+4.8

Scale: 1 (deficient) – 10 (outstanding)

#### 4.8 Discussion of Findings

Infrared control eradicated manual lid interaction, directly neutralising the chief contamination pathway. Mass and area reductions alleviated portage and spatial conflicts. Stylistic revisions slashed misuse by 77 %, corroborating HCD efficacy. Minor sensor reflectivity sensitivity and absence of autonomous power remain addressable in subsequent versions. Aggregate evidence confirms attainment of every stipulated performance benchmark.

## **CHAPTER 5**

### **CONCLUSION**

The investigation culminated in a functional automated receptacle that decisively rectifies the legacy unit's failings in recognisability, mass, spatial demand, and sanitary operation. Where the prior container invited abuse and contamination, the new device enforces correct, contactless disposal through integrated sensing, lightweight fabrication, and deliberate visual signalling.

#### **5.1 Objectives and Methodology Recap**

Diagnostic fieldwork, material re-specification, electronic integration, and comparative testing collectively satisfied the six stated objectives. Fifty corridor users recorded universal preference for touchless interaction and zero misidentification events.

#### **5.2 Key Achievements**

The unit now embodies affordance theory: its form and behaviour unambiguously direct appropriate action (Norman, 2013).

#### **5.3 Practical and Institutional Impact**

- Fifty deployed units could cut custodial contact points by 70 % and scattered litter by 60 %.
- Minimal servicing requirement.
- Transferable to clinics, markets, and rural health posts (solar variant feasible).

#### 5.4 Limitations

- Evaluation confined to indoor, dry conditions.
- Reliance on mains electricity.
- Single-stream capacity.
- Participant pool predominantly undergraduate.

#### 5.5 Future Recommendations

1. Photovoltaic charging coupled with ESP8266 telemetry.
2. Dual-chamber drum for source separation.
3. Polycarbonate lid with tamper sensing.
4. Six-month multi-site pilot involving twenty units.

#### 5.6 Physical Comparison (Old vs New Design)



## 5.7 Final Word

A once-ignored, misused object has become an unobtrusive yet effective agent of campus hygiene. The transformation underscores that thoughtful engineering with clear intent expressed through material, mechanism, and cue can resolve everyday problems at a modest cost.

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