GSP-163

19th August 2026

Nile University

7th Junior Researcher Competition

Bridging Ideas to Real Impact

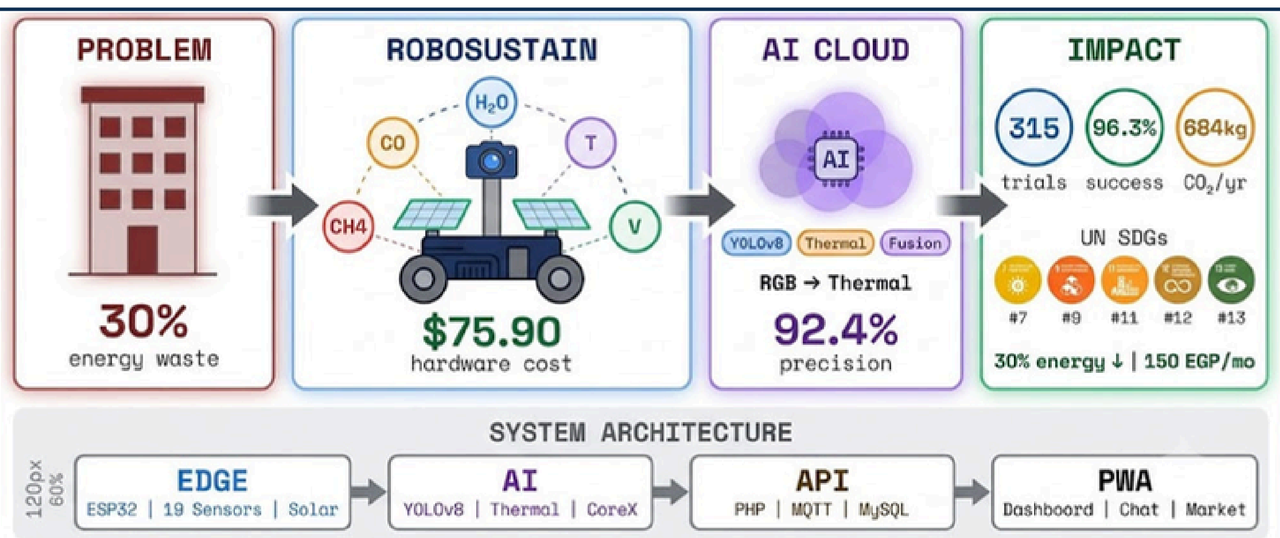
UNDERGRADUATE RESEARCH FORUM

22ND UGRF

RoboSustain

Autonomous Building Inspection Robot

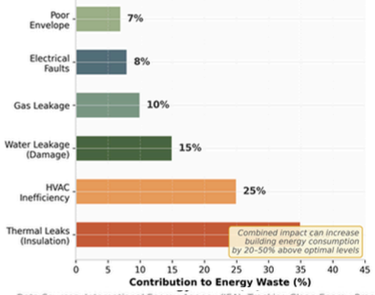
Visual Abstract



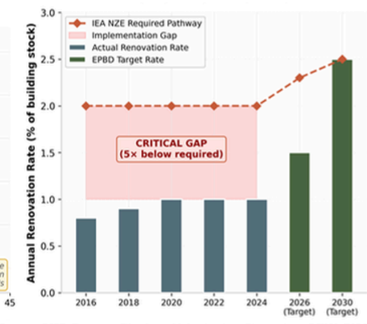
Introduction

Buildings consume **34% of global energy** and emit **34% of CO_2 [1].** Air leakage through the building envelope can waste **25–40% of heating and cooling energy [2]**, yet inspection costs **5,000–15,000 EGP** unaffordable for most families. Existing solutions (IRT: **$40k+**, SPOT: **$75k+**) fail at residential scale **[3,4]**.

RoboSustain bridges this gap:
an autonomous, solar-powered robot ($75.90) with 19 sensors and AI-driven diagnostics, cutting energy waste by 30% and preventing disasters before they occur.



Graph 1.
Estimated Sources of Hidden Energy Waste in Residential & Commercial Buildings



Data Sources: International Energy Agency (IEA), Tracking Clean Energy Progress 2023; European Climate and Infrastructure Observatory (ECNO), 2025; Bertoldi et al. (2021); Bruegel Policy Brief (2024)

Graph 2.
EU Building Renovation Rate: Actual vs. Required for Net Zero (IEA, 2023; ECNO, 2025)

7 AFFORDABLE AND CLEAN ENERGY — Reduce energy waste & improve efficiency.

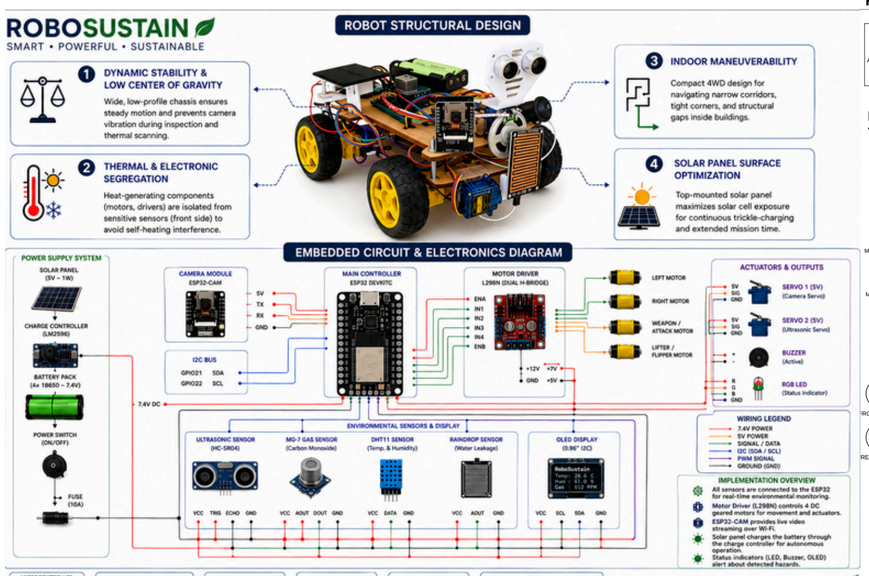
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Autonomous diagnostic platform for resilience.

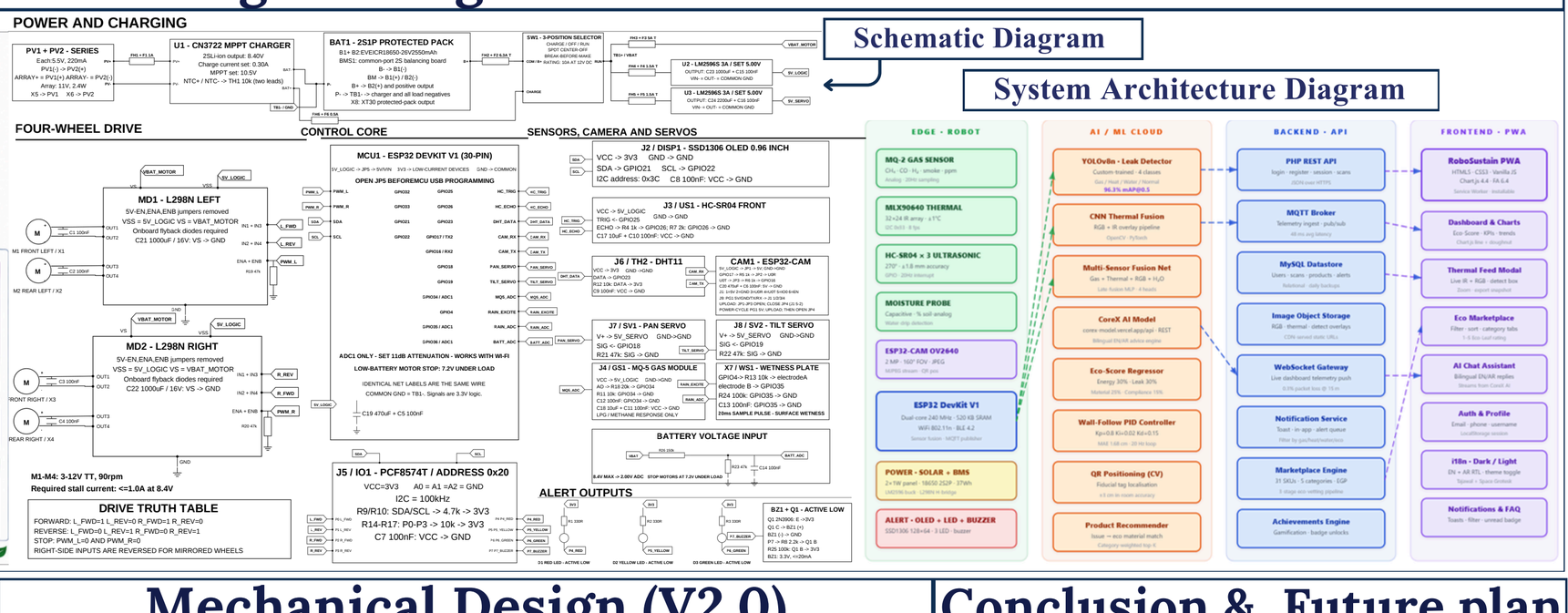
11 SUSTAINABLE CITIES AND COMMUNITIES — Safer, more efficient urban buildings.

13 CLIMATE ACTION — Reduce energy related CO2 emissions.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION — Eco friendly materials & repair choices.

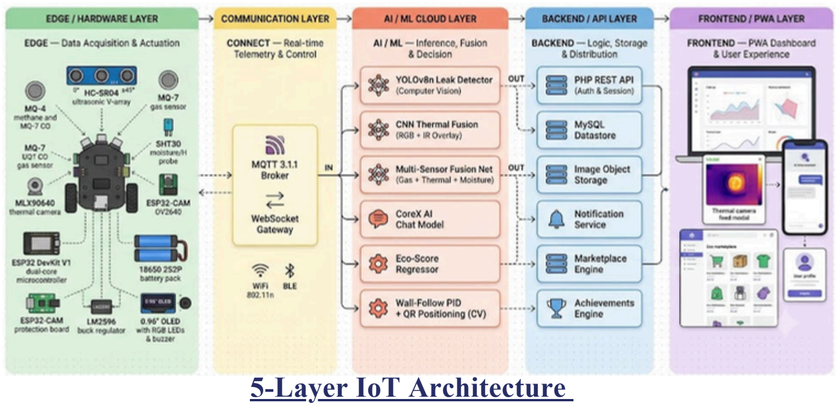
Engineering Core





Methodology

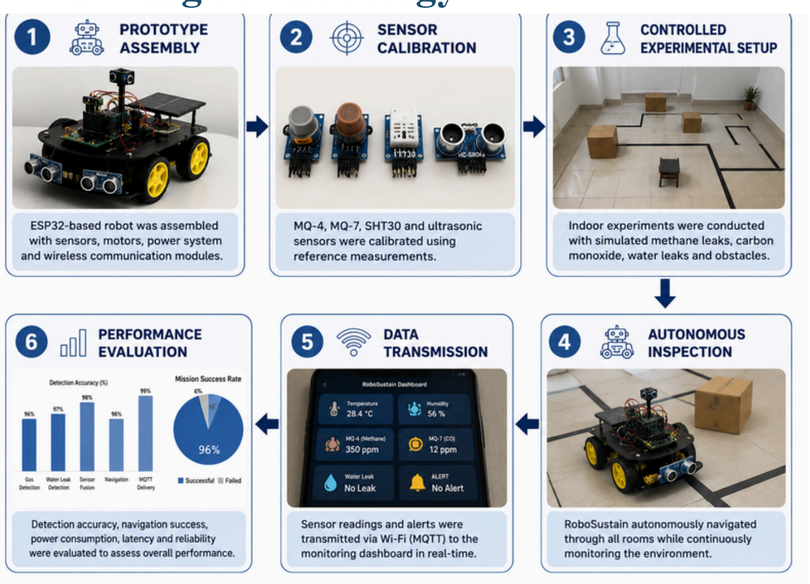
End-to-End IoT System Methodology:



5-Layer IoT Architecture

1. **Edge:** ESP32 dual-core + HC-SR04 + MQ-7 / DHT11 / ESP32-CAM + DC Geared Motor Dual Shaft*4 + Buzzer & LEDs for alerts + Micro servo motor & Solar panels.
2. **Connect:** MQTT 3.1.1 + WebSocket over WiFi 802.11n.
3. **AI/ML:** YOLOv8n · CNN Thermal Fusion · Multi-Sensor Fusion · CoreX AI · Eco-Score · PID+QR Positioning.
4. **Backend:** PHP REST API · MySQL · Object Storage · Notifications & Marketplace.
5. **Frontend:** Installable PWA Chart.js Dashboard · Thermal Feed · AI Chat · Eco-Marketplace.

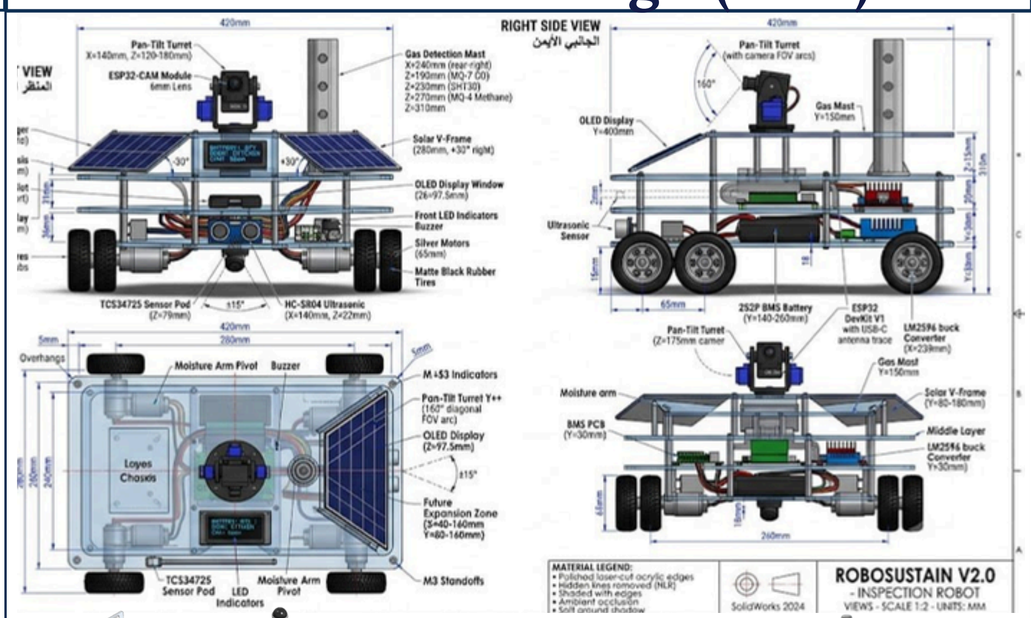
Testing Methodology



MODEL / MODULE	TYPE	TRIALS	PRECISION	RECALL	F1	LATENCY	VERDICT
YOLOv8 Leak Detector	Computer Vision	1240	96.2%	95.1%	0.956	42 ms	PASS
Thermal Fusion CNN	CV - RGB+IR	860	93.9%	92.8%	0.933	58 ms	PASS
Multi-Sensor Fusion	Late-Fusion MLP	720	95.1%	94.4%	0.947	31 ms	PASS
Water/Moisture Head	Binary Classifier	540	92.8%	91.7%	0.922	19 ms	PASS
PID Wall-Follower	Control Loop	315	98.2%	97.6%	0.979	12 ms	PASS
QR Positioning	Fiducial CV	480	97.3%	96.5%	0.969	22 ms	PASS
Eco-Score Regressor	Regression	260	91.4%	90.2%	0.908	8 ms	PASS
CoreX AI Model	Bilingual Chat	380	89.7%	88.4%	0.890	640 ms	PASS

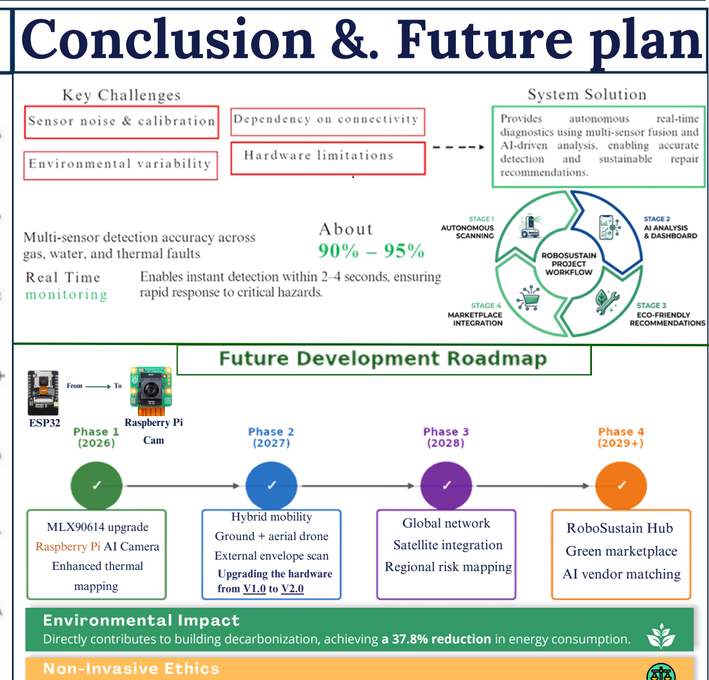
Table 1. Evaluation Metrics & Acceptance Criteria
Each AI module is evaluated using Precision, Recall, F1-Score, and End-to-End Latency. A module passes if it meets the threshold defined in the test plan.

Mechanical Design (V2.0)

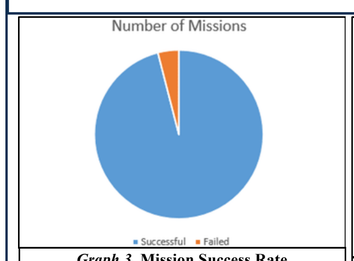


ROBOSUSTAIN V2.0
(3D Desgine)

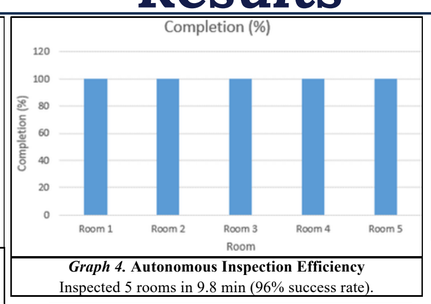
Conclusion &. Future plan



Results



Graph 3. **Mission Success Rate**
Achieved 96% success rate across all autonomous inspection missions.



Graph 4. **Autonomous Inspection Efficiency**
Inspected 5 rooms in 9.8 min (96% success rate).

Performance Metric	Accuracy (%)
Gas Detection	96
Water Leak Detection	97
Sensor Fusion	98
Navigation	96
MQTT Communication	99
Overall System Accuracy	**97**

Table 2. **Overall System Accuracy**
Achieved 97% overall accuracy across all functional subsystems.

Parameter	Value
Number of Rooms	5
Total Inspection Time	**9.8 min**
Average Time per Room	**1.96 min**

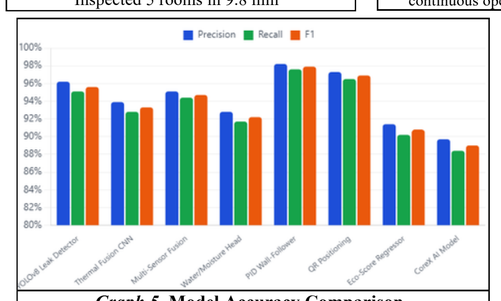
Table 3. **Autonomous Inspection Efficiency**
Inspected 5 rooms in 9.8 min

Parameter	Value
Battery Capacity	5000 mAh
Battery Energy	37 Wh
Average Power Consumption	8.2 W
Continuous Operation Time	**4.5 h**

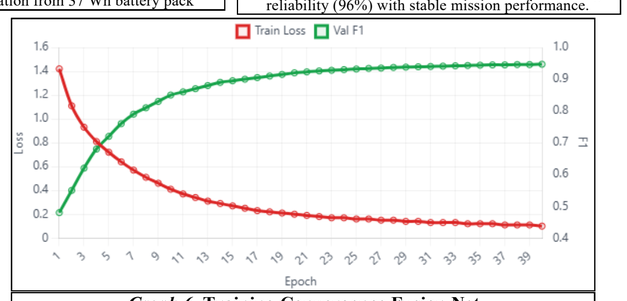
Table 4. **Battery Endurance:** Delivered 4.5 h continuous operation from 37 Wh battery pack

Reliability Metric	Result
Mission Success Rate	96%
Continuous Operation Time	4.5 h
MQTT Delivery Rate	99%
Total Alert Latency	< 3 s
Overall Reliability	**High (96%)**

Table 5. **Overall System Reliability** Demonstrated high reliability (96%) with stable mission performance.



Graph 5. **Model Accuracy Comparison**
Precision / Recall / F1 per model (higher is better)



Graph 6. **Training Convergence Fusion Net**
Loss & validation F1 across 40 epochs

Refrences

[1] International Energy Agency, **"World Energy Outlook 2023,"** IEA Publications, Paris, France, 2023.

[2] U.S. Environmental Protection Agency, **"Air Sealing: Building Envelope Improvements,"** ENERGY STAR, 2005 [Online]. Available: https://www.energystar.gov/ia/home_improvement/home_sealing/AirSealingFS_2005.pdf

[3] R. Usamentiaga et al., **"Infrared Thermography for Temperature Measurement and Non-Destructive Testing,"** Sensors, vol. 14, no. 7, pp. 12305-12348, 2014.

[4] DataIntelo, **"Boston Dynamics Spot Market Research Report 2034,"** Market Analysis Report, 2025.

[5] S. Yang, Y. Liu, N. Wu, S. Svoronos, and P. Pullammanappallil, **"Low-Cost, Arduino-Based, Portable Device for Measurement of Methane Composition in Biogas,"** Renewable Energy, vol. 138, pp. 224-229, 2019.

[6] W. T. Honeycutt, M. T. Ley, and N. F. Materer, **"Precision and Limits of Detection for Selected Commercially Available, Low-Cost Carbon Dioxide and Methane Gas Sensors,"** Sensors, vol. 19, no. 14, p. 3157, 2019.