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Implementing Mobile-based AI in Household Waste Type and Condition Classification

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Abstract- Urbanization and population growth have significantly increased waste generation, creating challenges for effective waste management and recycling. Improper waste sorting and management often results to unrecyclable waste contaminating recycling streams or recyclable waste ending up in landfill. This research presents a mobile-based waste classification application that integrates YOLOv11n for real-time object detection, and uses TensorFlow Lite with a Flutter-based user interface. The model was trained on a dataset of 4,410 images, which combines self-gathered images and images from Kaggle dataset. The images are then augmented to 10,936 images covering 23 waste classes, including organic, inorganic, hazardous, and residual types, with their recyclability conditions. The application allows users to detect objects using their phone camera, to identify their classification and condition, as well as receive actionable 3R (Reduce, Reuse, Recycle) recommendations. Evaluation results show a precision of 0.5963, recall of 0.60563, mAP@0.5 of 0.62246, and mAP@0.5:0.95 of 0.5279, indicating decent classification despite challenges posed by visually similar objects and variable backgrounds. Overall, the system demonstrates the feasibility of deploying a lightweight AI model on mobile devices in hopes of supporting proper waste segregation, increase user awareness, and potentially reduce contamination in recycling streams through practical waste classification.

Keywords: waste classification; YOLOv11; mobile application; tensorflow lite; user-oriented recycling guidance

1. INTRODUCTION

In this modern era, with the rapid pace of urbanization and population growth, waste generation has significantly increased worldwide, particularly in urban areas. Which becomes a problem as improper waste management contributes to environmental pollution, land degradation, and public health issues [1]. The “Throwaway Society” and the pattern of “take, make, use and dispose” in our modern lifestyle has created a dependency on single-use product, particularly in single-use plastic packaging, which has further worsened the waste generation problem [2], [3]. While efforts had been done to reduce the amount of waste generated by recycling wastes. Recycling streams are commonly contaminated with contaminated or dirty wastes or even contaminated with non-recyclable items, which reduces the effectiveness of recycling. As it often takes more effort and energy to recycle these contaminated wastes [4]. Waste is generally categorized into organic wastes (e.g., food, garden waste) which are biodegradable and inorganic wastes (e.g., plastics, metals, glass), which are wastes that require a way longer decomposition time [5]. An additional categorization of waste often includes hazardous and toxic waste (e.g., aerosol cans, electronics, medical waste), which are a type of waste that are unable to be recycled and need extra care in handling [6], [7], [8].

In Indonesia, household waste account for around 49.33% of the total waste, followed by market and commercial areas. The most prevalent materials of the waste generated are food waste (39.67%) followed by plastics (19.15%), and other materials [9]. Studies show that waste management in Indonesia is still a big challenge and requires coordinated strategies from start to finish, involving all stakeholders rather than relying on a single solution [10]. In several cities, like Bandung, Yogyakarta, and Mage[11]lang, plastic waste remains a serious problem due to weak coordination between formal and informal systems, low public awareness, and technical difficulties in recycling and waste processing [12]. According to Batam’s Regional Regulation No. 11 of 2013, waste management in Batam City begins at the community level or in other words from the source, where residents are expected to sort waste before disposing it. Residents are supposed to separate waste according to 3 main categories as per mentioned previously (organic, inorganic and hazardous or toxic wastes) into 3 different designated waste containers. Remaining waste is then collected and transported to Temporary Waste Disposal Site which then are transported to the Final Waste Disposal Site or also known as the landfill [13]. But despite this and the general awareness of 3R (Reduce, Reuse, Recycle) principles within the community, only a small portion of waste (around 16.53%) is actually managed according to the 3R principles [14]. A study shows that according to the Batam City’s residents, insufficient public education about waste management and the lack of practice of segregating waste may be the main reason for waste management issue in Batam city [15].

Therefore, community participation and public education is needed in managing waste. Community-Based Waste Management (CBWM) is an approach that involves the community in every stage of waste management, from reducing waste at the source, sorting, collecting, to reusing waste [16]. This approach aligns very well with the methods that are stated in the regional regulation. Where the community can sort waste and give recyclable waste to waste banks for reprocessing. By involving the community, the amount of waste produced can be reduced from the start, and waste management can be more effective. But the waste recycling process also cannot be sorted haphazardly, for example in plastic recycling, the plastic waste management procedure requires a sorting process, identification of plastic types, quality control, to avoid contamination that can reduce the effectiveness of recycling [4], [17].

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Recent studies have explored the usage of artificial intelligence (AI) in waste classification and management. AI based system has been proposed to differentiate between organic and inorganic waste, aiding sorting behaviour in hopes of reducing contamination in recycling streams [18]. Additionally recent studies have shown YOLO's effectiveness in real-time image classification and object detection, demonstrating its feasibility for mobile-based waste classification using lightweight variants like YOLOv11 [19]. Mobile-based AI offers a practical solution to these challenges by allowing real-time waste classification and providing users with easy access to information regarding actionable recommendations about recycling [20], [21]. By deploying AI models on mobile devices, individuals can sort waste correctly before disposal, reducing the amount of recyclable material reaching landfills. Previous studies also have demonstrated the effectiveness of mobile AI systems in waste management. For instance, an Android application was developed using convolutional neural networks (CNNs) for waste type detection, achieving high precision and recall for household waste categories [22]. Others implemented CNN-based models within the CRISP-DM methodology for structured data mining and mobile deployment, accurately classifying organic and inorganic wastes [23]. There is also a study that integrated a PyTorch-based classification model with a Tkinter interface to provide recycling recommendations, and there is also a study that combined deep learning with blockchain to provide verified guidance on proper recycling practices [21], [24]. YOLO (You Only Look Once) is a single-stage object detection model optimized for real-time applications. YOLOv11n is the nano variant of the YOLOv11 family. YOLOv11n is designed to prioritize inference speed and low computational cost. Studies show that YOLOV11n had the highest inference speed and lowest latency among the YOLOv11 variants, making it suitable for real time detection in mobile applications [25]. Studies also show that lightweight YOLO models can be converted and deployed using TensorFlow Lite for mobile applications, allowing real time object detection on smartphone with reduced latency [20]. In addition to that, YOLOv11 has been applied in waste classification task and shown to detect multiple waste category effectively [26].
But despite these advancements, the prior researches have often focused solely on classifying waste by type (e.g., plastic, glass, metals, etc.), without considering whether the detected waste is still suitable for recyclable or has become residual/non-recyclable. In real-world waste management practices, inaccurate sorting decisions can cause contaminated, damaged, or residual waste that are unable to be recycled to be mixed with the recyclable materials. Which can contribute to a higher contamination rate at recycling facilities or waste bank that can often reduce the efficiency of recycling [4]. That is why proper identification between recyclable, dirty, and residual waste is important. Some waste items may be made of recyclable materials but become unsuitable for recycling due to heavy contamination or damage. These items should be handled using other treatment methods instead of being sent for recycling. Without considering waste condition, waste sorting systems may encourage incorrect disposal and reduce recycling efficiency.
Therefore, this study aims to develop a mobile-based application for waste classification using YOLOv11n for real-time object detection and Flutter for the user interface, with the trained model deployed using TensorFlow Lite for efficient mobile deployment. The proposed application is able to classify detected waste base on both material type and its condition (recyclable, dirty, or residual) and maps each class to its appropriate 3R-based recommendations. By combining waste type and condition detection, with mobile deployment, this study hopes to provide one of a practical solution to support community-based waste management practices, improving waste segregation behaviour, reduce recyclable waste contamination, as well as reduce the number of recyclable materials sent to landfills.

2. RESEARCH METHODOLOGY

2.1 Research Model and Methodology

This research uses case study and applied approach. The case study is focused on analyzing the data on waste management in Batam city as well as researching on the different categorizations of wastes as well as their conditions. While the applied approach aims to develop a solution in the form of a mobile application that can assist with the classification of waste. As well as providing actionable mapping-based 3R (Reduce, Reuse, Recycle) actions that can be taken that takes account of the waste's current condition to raise public awareness for proper waste segregation and proper waste management. This study is done by following the research model of Alden [23] which is modified slightly to suit the objective of this research, as shown here in Figure 1.

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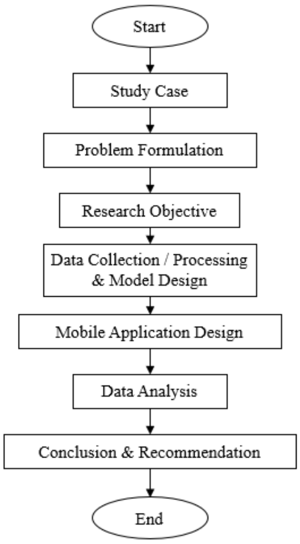

Figure 1. Research Flow Diagram

In the Data Collection/Processing & Model Design phase and Mobile Application Design, the methodology used is CRISP-DM. This methodology is also based on the model used by Alden [23] which is slightly modified to fit with the objective of this research, which can be seen in Figure 2.

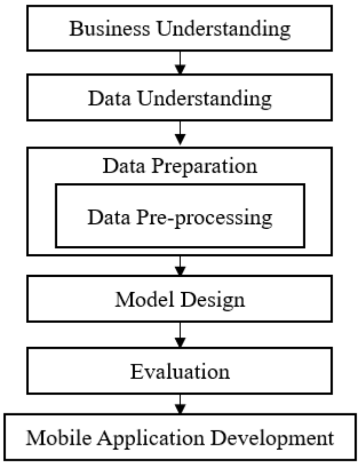

Figure 2. CRISP-DM Methodology

2.2 Data Preparation and Model Design

The dataset used for this research was sourced from various sources which is TrashNet Dataset [24], Recyclable and Household Waste Classification Dataset [27], Garbage Dataset [28] and self-captured images of household waste. The collected images cover a variety of waste types, including plastics, paper, metals, glass, organic materials, food waste, rubber, electronic waste, hazardous wastes, and residues. As well as their corresponding recyclability conditions: recyclable, dirty, and residue. Each image was labeled in Roboflow according to its category, type and recyclability condition, in which it is labelled across 23 classes as shown defined in Table 1. The sample dataset images for each class can be seen in Figure 3.

To improve the model's robustness, the labelled dataset is augmented in Roboflow, applying transformations such as rotation, scaling, brightness adjustment, and flipping. Then the augmented dataset is split 80% into training, 10% into validation and 10% into testing. It is exported with YOLOv11 image and annotation format. The model for this study uses YOLOv11 with the nano (n) variant, which is selected for its balance between detection accuracy and computational efficiency which in theory make it suitable for mobile deployment when converted to TensorFlow Lite format. The model is trained on the augmented dataset using standard hyperparameters and data augmentation techniques.

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a) Organic compost
b) Organic recycle
c) Glass dirty
d) Glass recycle
e) Paper (compound) recycle
f) Paper (compound) dirty
g) B3-electronic recycle
h) B3-electronic dirty
i) B3-electronic residue
j) Metal recycle
k) Metal dirty
l) Plastic recycle
m) Plastic dirty
n) Plastic hard to recycle
o) Non organic residue
p) B3-waste recycle
q) B3-waste dirty
r) Fabric recycle
s) Fabric dirty
t) B3-waste residue
u) Composite
v) Rubber recycle
w) Rubber dirty

Figure 3. Collected Dataset Sample Images

2.2 Mobile Application Design

This study uses Flutter for the development framework of the application's user interface. The mobile application's interface includes a Home Page, Camera Page and a Trashlog Page. The Home Page provides an overview of waste categories and includes information on recycling facilities or waste banks. A banner encourages users to engage in trash tracking to the trash log, which allows users to monitor their personal waste generation over time. The Camera Page serves as the primary detection interface. Users can capture images or use the live camera feed for real-time object detection. Additionally, an image picker feature allows users to upload existing photos for detection. Finally, the Trash Log Page serves as a tool for tracking the user's waste generation. The application also implements a mapping-based recommendation system, which links each detected waste type to a predefined recycling category, which also can be seen in Table 1.

Table 1. Class Definitions and 3R Mapping

Class Name	Class Definitions and Example	Actionable 3R (Reduce – Reuse – Recycle) Mapping in Application
***Organic* OCompost**	Compostable organic waste. Such as food waste, wet paper, lawn waste, etc.	*Reduce*: Produce less food waste by using all edible parts of food *Reuse/Recycle*: Composting food waste/lawn waste
***Organic* ORecycle**	Clean recyclable dry organic waste. Such as newspaper, cardboard, etc.	*Reduce*: Buy less organic packaging that can create recyclable organic waste. Buy less newspaper/paper products that can produce this type of waste *Reuse*: Reusing existing cardboard, newspaper/paper materials for crafts/packaging *Recycle*: Separate/gather and pack clean recyclable organic material and send it to a recycling facility/waste bank for recycling
***Inorganic* NPlastic Recycle**	Clean and separated plastic wastes. Such as plastic bottles, squeeze bottles, jars, etc.	*Reduce*: Buy less products that creates this waste, by using existing material or reusable/compostable alternative, like reusable bottles, reusable jars, etc. *Reuse*: Reusing existing plastic containers for storage or for crafts materials *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling

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Inorganic **NPlastic HR (Hard to Recycle)**	Clean and separated plastic wastes that are often considered harder to recycle. Such as plastic cutlery, plastic bags, plastic labels, etc.	*Reduce*: Buy less products that creates this waste, by using existing material or reusable/compostable alternative, like reusable bags, reusable utensils, etc. *Reuse*: Reusing existing usable hard to recycle plastic wastes, such as reusing plastic bags that still can be used for storage/as garbage bags/reusing plastic wastes for craft materials. *Recycle*: Separate/gather and pack clean recyclable waste and send it to a recycling facility/waste bank for recycling. Some waste banks may accept this type of waste if packed properly. Some waste banks also only accept plastic bag waste in this category when turned into eco-bricks [29]
Inorganic **NPlastic Dirty**	Dirty plastic waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less products that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Waste in this category can be cleaned first before be used again/be used for craft material *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling
Inorganic **NMetal Recycle**	Clean and separated metal waste. Such as aluminum cans, tin, etc.	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Reusing existing usable metal containers and or use metals for craft materials *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
Inorganic **NMetal Dirty**	Dirty metal waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Waste in this category can be cleaned first before be used again/be used for craft material *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling
Inorganic **NGlass Recycle**	Clean and separated glass waste. Such as glass bottles, jars, glass containers etc.	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Reusing existing usable glass containers for storage and or use glass waste for crafting materials *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
Inorganic **NGlass Dirty**	Dirty glass waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Waste in this category can be cleaned first before be used again/be used for craft material *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling
Inorganic **NRubber Recycle**	Clean and rubber waste. Such as rubber gloves, tires, rubber bands, etc.	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Reusing existing usable rubber for crafting materials *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
Inorganic **NRubber Dirty**	Dirty rubber waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Waste in this category can be cleaned first before be used again/be used for craft material *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling
Inorganic	Clean and separated compound paper waste. Compound paper refer to	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative

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NPaper Compound (Cmp) Recycle	paper products that are lined with plastic which cannot be entirely be considered organic. Commonly used for products such as milk cartons, juice box, paper food wraps, etc.	*Reuse*: Reusing existing usable compound paper material for crafting materials *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
***Inorganic* NPaper Compound (Cmp) Dirty**	Dirty compound paper waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: Waste in this category can be cleaned first before be used again/be used for craft material *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling
***Inorganic* NFabric Recycle**	Clean and fabric waste. Such as clothes, rags, etc.	*Reduce*: Buy less product that creates this waste, by always using usable existing clothes when possible than buying new one *Reuse*: Reusing existing usable fabrics for patching/repairing other fabric materials or using scrap fabrics to make collages or mats/cleaning rags *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
***Inorganic* NFabric Dirty**	Dirty fabric waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by always using usable existing clothes when possible than buying new one *Reuse*: Waste in this category can be cleaned first before be used again/be used for craft material *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling
***Inorganic* NAResidue**	Unrecyclable or broken-beyond use inorganic waste. Such as dirty broken up plastic waste, small unrecyclable waste, etc. Which take more effort and energy or often impossible to recycle.	*Reduce*: Buy less product that creates this waste, by always using usable existing material or switching to reusable/compostable alternative *Reuse*: This type of waste is often unable to be reused *Recycle*: This type of waste is often unable to be recycled
***Inorganic* Composite**	Uncategorized waste, this type of waste combines different materials together, so are often considered unrecyclable, and just tossed away to landfill. But some facilities may still accept waste from this category.	*Reduce*: Buy less product that creates this waste, by always using usable existing material or switching to reusable/compostable alternative *Reuse*: Always repair/reuse repairable composite waste if possible before buying a new one *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling (Some might accept)
***Hazardous* B3Electric Recycle**	Clean recyclable electrical wastes. Such as Electronics, Appliances, Batteries, Cables, etc.	*Reduce*: Buy less product that creates this waste, by always using existing usable electronics when possible than buying new one *Reuse*: Always repair/reuse repairable electronics if possible before buying a new one *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
***Hazardous* B3Electric Dirty**	Dirty electrical waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by always using existing usable electronics when possible than buying new one *Reuse*: Clean first, and always repair/reuse repairable electronics if possible before buying a new one *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling. Handle waste in this category with care
***Hazardous* B3Electric Residue**	Unrecyclable broken or hazardous electrical waste. Such as broken or leaking battery, rusted appliances or	*Reduce*: Buy less product that creates this waste, by always using existing usable electronics when possible than buying new one *Reuse*: This type of waste is too dangerous or too laborious to repair/reuse

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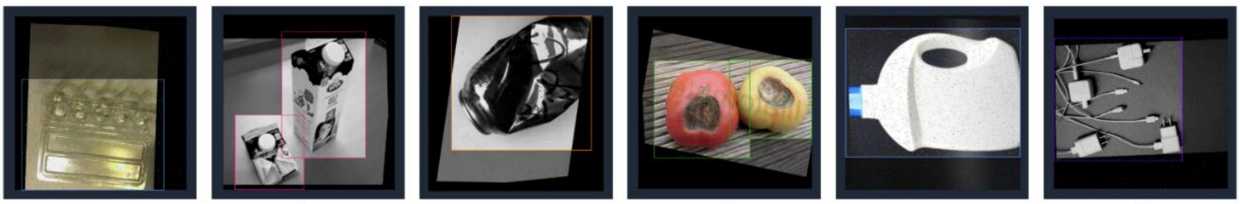
	electronics. Which take more effort and energy or often impossible to recycle.	*Recycle*: This type of waste is often unable to be recycled
***Hazardous* B3WasteHr Recycle**	Clean but often hard to recycle, some facilities accept this type of waste. Such as ceramics, aerosol cans, etc.	*Reduce*: Buy less product that creates this waste, by using existing material or reusable/compostable alternative *Reuse*: (Some) Waste in this category can be used again/be used for craft material (specifically pottery/porcelains) *Recycle*: Separate/gather and pack clean recyclable waste in this category and send it to a recycling facility/waste bank for recycling
***Hazardous* B3WasteHr Dirty**	Dirty hard to recycle B3 waste, either contaminated by food waste or dirt, and or not separated by its subcategory (label). Must be cleaned before recycling to avoid contamination	*Reduce*: Buy less product that creates this waste, by using existing material/reusable/compostable alternative *Reuse*: (Some) Waste in this category can be cleaned first before be used again/be used for craft material (specifically pottery/porcelains) *Recycle*: Separate/gather and clean the waste in this category first before packing it to be sent to a recycling facility/waste bank for recycling. Handle waste in this category with care
***Hazardous* B3Waste Residue**	Unrecyclable or hazardous wastes. Waste such as medical waste, sanitary waste, or other hazardous wastes. Diapers, medical mask, medical syringe /needles, medical gloves, cigarette butts, etc. all fall into this classification	*Reduce*: This type of waste can be reduced by using alternative recyclable or compostable materials, but is often hard to find *Reuse*: This type of waste is unable to be reused *Recycle*: This type of waste is unable to be recycled

3. RESULT AND DISCUSSION

3.1 Dataset Preparation and Model Design

This study's dataset comprises 4,410 images, which are then labelled based on the categorization from Table 1 and augmented using Roboflow to generate 10,936 images. The Preprocessing included automatic orientation correction, resizing to 640×640 pixels with black padding to maintain aspect ratio, and contrast enhancement using contrast stretching. The Augmentation method used in Roboflow were horizontal and vertical flips, rotations of 90° in multiple directions, random cropping with 0–30% zoom, minor rotations between -15° and +15°, shear transformations, grayscale conversion for 25% of images, and color adjustments for hue, saturation, brightness, and exposure. Additionally, noise and blur were applied to simulate realistic image quality variations. Each original image generated three augmented variants, creating a sufficiently diverse dataset that allows the model to generalize across different scenarios and environments. The sample of the final labelled and augmented dataset image can be seen in Figure 4. The dataset is then split into 3 sets. The training set (80%) with a total image count of 8,749, validation set (10%) with a total image count of 1,094 and test set (10%) with a total image count of 1,093.



a b c d e f

a) Plastic recycle b) Paper (compound) recycle c) Metal recycle d) Organic compost e) Plastic recycle f) B3-electronic recycle

Figure 4. Final Labeled & Augmented Training Sample Images

The model was trained based on the final dataset which was exported in YOLOv11 image and annotation format with 23 classes in total. The training process was done on Goggle Colab using the runtime environment NVIDIA Tesla T4 GPU to support efficient training. The model was trained using the Ultralytics YOLOv11n architecture with pretrained weights (yolov11n.pt) and the model was trained for 50 epochs with an input image size of 640 x 640 pixels and a batch size of 16, which are summarized in the table 2 below.

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Table 2. Model Training Configuration

Parameter	Value
Training Platform	Goggle Colab (NVIDIA Tesla T4 GPU)
Framework	Ultralytics YOLO
Pre-trained Weight	yolov11n.pt
Number of Classes	23 Classes
Training Epoch	50 Epoch
Batch Size	16
Image Size	640 x 640

3.2 Model Evaluation

After training, the model's evaluation on the validation set yielded the following metrics as shown in Table 3. The result indicates a reasonable balance between accuracy and robustness. The confusion matrix for the model can be seen in Figure 5. The result shows that the model performs well for several waste classes with clear visual characteristics such as recyclable electric waste, rubber waste, recyclable organic and compostable wastes, where a high true positive value are observed. This shows that the model is able to identify waste types with distinctive features correctly. However, the model still exhibits confusion between conditions with similar visual appearances. This is caused by overlapping visual characteristic, varying lighting conditions and background clutter, which are common in real world mobile environment. Additionally, a high number of background predictions indicate missed detections and false positives, particularly for small, partially covered, or poorly lighted waste images. Despite this, several waste classes and their conditions are still being correctly recognized by the model. This demonstrates the model's potential for practical mobile-based waste classification, though further improvement of the model can be achieved through thorough dataset refinement.

Table 3. Evaluation Matrix of the Best-performing Model

Metric	Value
Precision	0.5963
Recall	0.60563
mAP@0.5	0.62246
mAP@0.5:0.95	0.5279

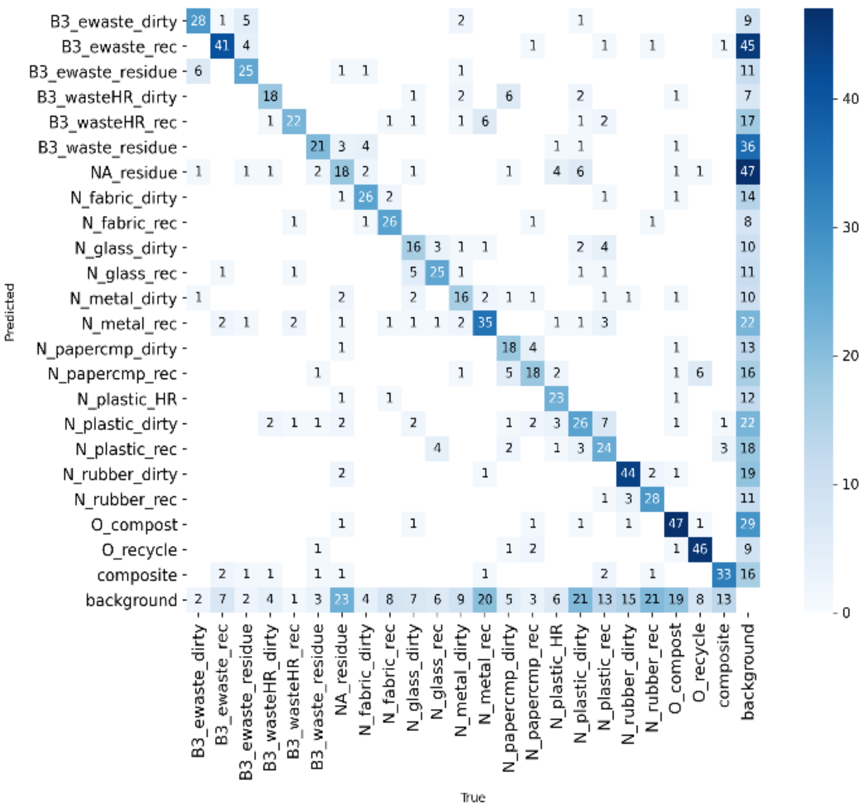

Figure 5. Confusion Matrix of the Model

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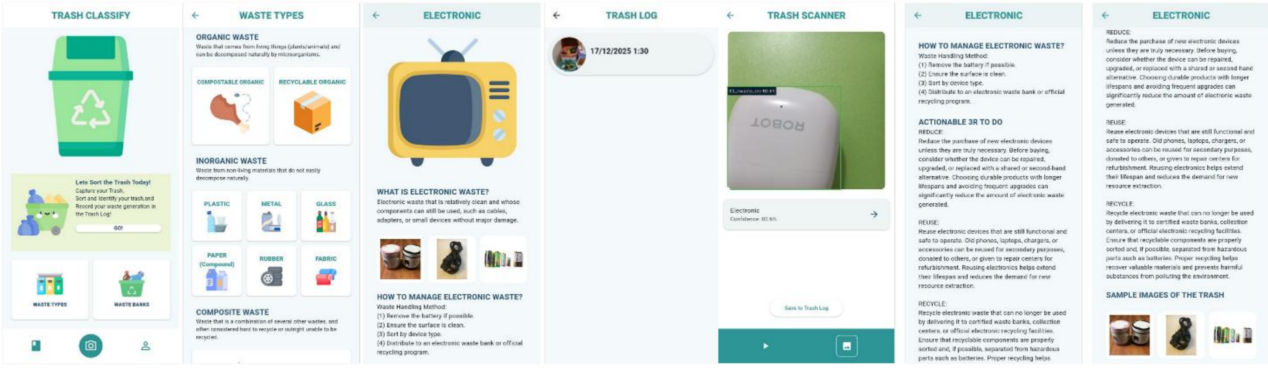
3.3 Mobile Application

After the model is developed, the best-performing model was then exported to TensorFlow Lite format using the Ultralytics framework. The conversion used an input image size of 640×640 pixels and included non-maximum suppression (nms) to enable efficient use on mobile devices. Which then is saved as best_float32.tflite file format. The mobile application is developed using Flutter. The user interface of the mobile application can be seen in Figure 6. The developed application features a functioning Home Page (Fig. 6a), Waste Information Page (Fig. 6b), Details Page (Fig. 6c), Camera Page (Fig. 6e), Trash Log Page (Fig. 6d), and Detection Page (Figs. 6f-6g). The Home Page serves as the starting point for users to use the application. It features informational pages regarding different waste types and waste banks, which users can click to learn more about waste categories, recycling practices, and information regarding waste banks or waste management facilities, and this can encourage proper waste management behavior in communities by educating users. The Home Page also includes a banner that encourages users to start tracking their trash generation through the Trash Log feature, so users are motivated to record the waste they generate on a daily basis, which can help raise awareness of their own waste generation and gradually make them more conscious of their disposal habits, potentially leading users toward reducing waste and adopting a zero-waste mindset.



a b c d e f g

Figure 6. Mobile Application User Interface

The Waste Information Page contains multiple categories of waste materials, and users can select each category to be directed to the Details Page, where they can learn more about what defines waste in that specific category, common examples, and proper waste management procedures regarding that category. The Camera Page serves as the main page for waste detection, featuring a pause and play mechanism that allows users to temporarily stop the camera feed to make it easier to detect and classify waste objects accurately. It also includes an image picker feature, enabling users to select images directly from their phone gallery and perform waste detection on saved images, which provides flexibility in how the application can be used. In addition, the Camera Page provides a save-to-trash-log button so detected waste can be recorded and stored in the Trash Log Page, which serves as a simple tracking page to record waste generation over time and support the development of a zero-waste mindset. From the Camera Page, users can also be directed to the Detection Page, where the application displays the detected waste category along with information about the condition of the waste, recommended handling methods, and suggested 3R (Reduce, Reuse, Recycle) actions, allowing users not only to identify waste but also to understand how to manage it properly according to its condition and material type.

The application is able to detect objects in real time, although inference on mobile devices exhibits moderate latency. As can be seen Figure 7, the application is able to detect objects be it single or multiple objects simultaneously during testing. But there are some limitations when testing for pictures/real-time detection of multiple objects. The model's performance can be affected by busy or cluttered backgrounds, as well as by poor or uneven lighting conditions, which may cause the model to miss the detection or confuse objects that have similar visual characteristics to each other. This issue is particularly noticeable when multiple objects are in frame and have similar visual characteristics. In real-world application, this condition is hard to avoid, as waste is often found in uncontrolled and messy environments with complex backgrounds. But despite these challenges, the application still manages to provide an interactive and informative interface that allows users to identify and learn about different types of waste and the general appropriate actions for managing them. The integration of detection results with educational content and 3R recommendations helps ensure that even when detection confidence is affected, users still receive useful guidance on proper waste handling Overall, the results demonstrate that the proposed system is feasible for mobile deployment while acknowledging the current limitations of the model in handling complex backgrounds and visually similar waste objects. With further improvements in model training, dataset diversity, and optimization of the application, the system hopefully is able to become a practical and educational tool for helping users better understand waste classification and proper waste management practices in everyday situations.

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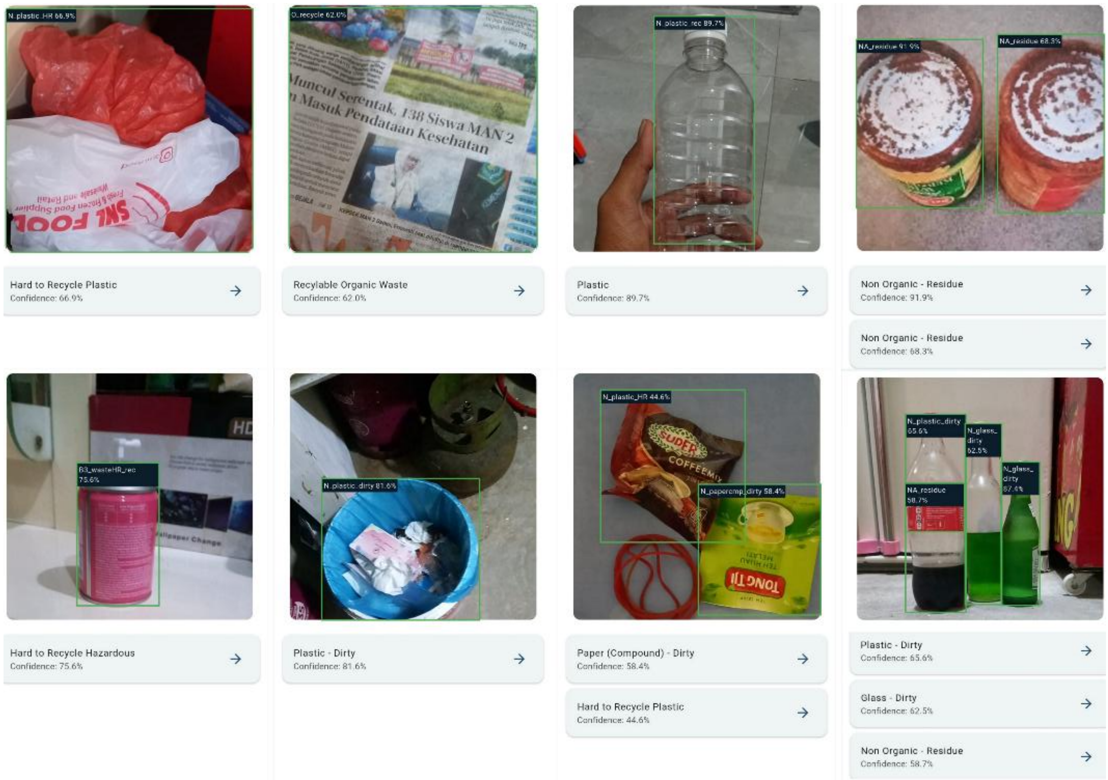

Figure 7. Test for Trash Classification and Identification

4. CONCLUSION

Overall, this study demonstrates the practical application of mobile AI to support improved waste management practices. The developed system which is built using YOLOv11n for object detection and Flutter as the user interface, with TensorFlow Lite to convert the model, was successfully able to integrate real-time object detection, waste classification, and 3R-based guidance, providing users with actionable information for proper disposal and recycling. Testing results show that the model is able to decently detect several waste types with distinct visual characteristic, as shown by the evaluation metrics with a precision value of 0.5963, recall of 0.60563, mAP@0.5 of 0.62246, and mAP@0.5:0.95 of 0.5279. However, challenges still remain for detecting some visually similar waste conditions, particularly under poor lighting, clutter background, or partially covered images, as well as experiencing from moderate latency on mobile devices. These limitations reflect common constraints in lightweight vision-based models deployed on mobile platforms. Despite these limitations, the system successfully addresses the research objective by combining waste type and condition detection with recyclability status and 3R-based recommendations, providing users with practical and consistent guidance for waste sorting in real-world scenarios. Future work may focus on improving the model's robustness through dataset expansion, additional waste categories for finer classification, enhanced augmentation and optimization for mobile inference can be explored to further improve detection reliability, system responsiveness, and user engagement.

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